NATURAL PHILOSOPHY.

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PREFACE.

THIS Treatise on Natural Philosophy differs from others in the large number of practical experiments and exercises which it contains. The authors believe that students of science should be, as far as possible, investigators, and, to encourage the spirit of research, they have given suggestions tending to lead them on in this way. The experiments can nearly all be performed with very simple and inexpensive materials, such as any school or home can furnish. More elaborate instruments are described for the benefit of classes which have access to them. The book can also be used by classes which have not time to perform the experiments. Yet it is strongly recommended that as many as possible be tried.

Two sizes of type are used through the book. The matter printed in large type will form a complete elementary course, and the whole book a more exhaustive one. Those who take the former are advised to include as many as convenient of the experiments, exercises, and questions. The large number given will allow the teacher to make selections suited to the ability of the class.

The use of technical terms, except where they seemed necessary to the better comprehension of the subject, has been avoided. It has been recognized that the majority

of students of natural philosophy have no use for these terms. What they want is a practical knowledge of the subject and the cultivation of scientific habits of mind.

The methods of the leading scientific men of the present time have been incorporated, and their instruments described and figured. In any treatise on the subject which embraces an account of these methods, the doctrine of the conservation of energy must have a prominent place. The great advances in practical science within the last few years, especially in sound, electricity, and meteorology, have also been utilized so far as they seem to bear on the principles.

NOTE TO REVISED EDITION.

In the present revision, made by C. Canby Balderston, of Westtown School, Pennsylvania, the chapter on Electricity has been entirely rewritten, with a view of making it represent as nearly as possible the present state of the science. The chapters on Matter, Motion and Force, and Light have been largely rewritten and rearranged, experience in the use of the book having suggested some changes. The subject of surface-tension has been introduced into the chapter on Liquids, and the naphtha-engine is described in the chapter on Heat.

As a new feature, a summary of each chapter has been added, which cannot fail to assist the student in gaining a clear conception of the subject.

CONTENTS.

NATURAL PHILOSOPHY.

CHAPTER I.

MATTER.

1. **What is Matter?**—All the bodies and substances which occupy space, the stars and the planets, rocks, water, and air, and everything we can see or feel, is composed of *matter*.

We can crumble a rock or divide a quantity of water into smaller portions. These can again be subdivided, and all the fragments will resemble the original in their properties. There is a practical limit to this subdivision, arising from the imperfection of our senses or our tools, but we may *suppose* it carried on till the very smallest possible fragments remain which possess the properties of the substance.

2. **Molecules.**—To these fragments we give the name molecules. They are definite quantities of matter, which have size and weight.

Hence *a molecule is the smallest portion of any substance in which its properties reside.*[1] All matter is made up of molecules. We know that molecules must be extremely small. Sixteen ounces of gold, which in the form of a cube would not measure an inch and a quarter on a side, can be spread out so that it would gild silver wire sufficient to reach round the earth. Its thickness must then be at least

[1] The properties of matter are those qualities which are peculiar to it,—which belong to it and to nothing else.

one molecule, and is doubtless many. In odors, which produce sensation by invisible particles, the molecules scatter about through the atmosphere for years without apparently diminishing the size of the substance from which they are separated. Microscopists have found animals so minute that four million of them would not be so large as a single grain of sand, yet each has its organs and its circulating fluids.

3. **Size of Molecules.**—No molecule of any substance is large enough to be visible, even in the most powerful microscope. It is only by the most careful experiments that any notion of the size of molecules can be formed, and the results of such experiments indicate that they are minute beyond our comprehension. Sir William Thomson estimates that if a drop of water as large as a pea were magnified to the size of the earth, the molecules would then appear scarcely larger than the original drop.

The spaces between the molecules of matter are believed to be much larger than the molecules themselves.

4. **Atoms.**—It is not possible to divide a molecule by pounding or grinding, but by means of heat or some other chemical agent most molecules may be separated into two or more portions. Each of these is called an atom; and this cannot be further divided. The word atom means indivisible.

5. **Elements and Compounds.**—The atoms of some substances are all alike,—that is, the substance is composed of one kind of matter only, which cannot be separated into other kinds. Such a substance is called an *element*. About seventy elements have been found on the earth. Examples: iron, gold, silver, carbon, hydrogen, oxygen. Most of the substances which we see are *compounds* of two or more of the elements. Water is composed of hydrogen and oxygen; wood, cotton, starch, sugar, are composed of hydrogen, oxygen, and carbon. Salt is composed of chlorine and sodium.

6. The elements in a compound are generally very differ-

ent from each other and from the compound. The science of chemistry treats more fully of the elements and their union into compounds. Here are two chemical experiments.

Experiment 1.—Dissolve a little baking- or washing-soda in water and pour in some vinegar. Bubbles of gas come out.

A molecule of soda is composed of a number of atoms of different substances. The acid in the vinegar causes a division of the molecule, forming new substances. One of these substances (carbonic acid) is a gas, which passes off into the air. The others remain in the vessel.

If a small portion of sugar be burned on a stove, a black substance will remain. A molecule of sugar is composed of forty-five atoms of three different kinds,—carbon which we can see as charcoal, and hydrogen and oxygen, which are colorless invisible gases. Heat separated the atoms of the molecules; the gases passed off into the air, and the solid carbon remained.

7. **Matter Indestructible.**—If the escaping gases and the carbon of the last experiment could be weighed, the sum of the weights would be found to be just equal to the weight of the original sugar. Hence we arrive at an important property of matter,—*it is indestructible.*

There are many cases of the apparent destruction of matter in combustion and chemical action, but all that is done is to change its form. The molecules are divided, and the atoms form new combinations, some or all of which are invisible. In all the various changes continually going on, in our furnaces and laboratories, and in nature, not a new atom is ever created. According to the best of our knowledge, the amount of matter in the universe has remained unchanged since the original creation.

8. **Matter Porous.**—The molecules of matter do not fit closely together. Hence open spaces, or pores, are left between them. We then arrive at a property of matter which is believed to be universal,—*it is porous.*

Experiment 2.—Fill a tumbler with cotton-wool, pressing it down so firmly that the vessel will hold no more. Now remove the cotton and fill the vessel with alcohol. With care, the cotton may all be replaced without spilling the alcohol. The cotton has gone into the pores of the alcohol, and the alcohol into the pores of the cotton. It is impossible to conceive that the molecules of both substances occupy the same space.

9. **Matter can be Expanded and Compressed.**—As a resul of the porosity of matter, it is possible to *expand* or to *com press* it. The molecules are not changed in form or size but they are further separated in expansion, and crowde together in contraction, so that the substance becomes mor porous in one case and less so in the other. Heat in genera separates the molecules from one another. A ball that wil just go through a ring when cold will not do so when heated The mercury in a thermometer-tube rises in hot weathe because the heat separates the molecules and there is n chance for expansion in any other direction. The end of the rails of a railroad-track which touch each other in summer are separated in winter. A nail can be drive into wood because it causes a compression of the molecule around to make a place for it.

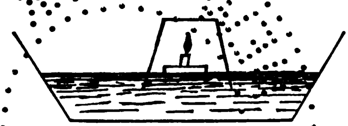

FIG. 1.—EXPANSION BY HEAT.

Experiment 3.—On a cor floating on water place a shaving Set it on fire, and put over it a inverted tumbler. The heat the combustion will expand t air in the tumbler and force out under the edge; what is l will quickly cool and contract, that almost immediately the water will rise into the tumbler.

10. **Malleability and Ductility.**—Malleable substances such as can be hammered or rolled into sheets. Duc substances are such as can be drawn into wire. In tl cases the molecules slide past one another and arra themselves differently. This motion of the molecul not possible in all solid bodies, and some possess it much higher degree than others. Gold may be ham out into sheets less than $\frac{1}{200,000}$ of an inch in thi Copper, silver, and tin can also be beaten out int thin foil.

One of the substances which may most readily b out into wires is glass. Heated red-hot in an alco or hot gas flame, a small glass rod or tube may b out into a very fine thread.

Metal wire is made by drawing the soft metal through holes, each one smaller than the preceding. Platinum wire can be reduced so that it will be finer than the finest hair.

11. **Elasticity.**—Almost all bodies and all substances are more or less *elastic;* that is, when forced into a different size or shape,—some by compression, some by stretching, some by bending or twisting,—the molecules tend to resume their positions with reference to one another, and restore the substance to its shape or size.

Experiment 4.—Let a rubber ball fall on a dusty, varnished table-top. Notice the size of the mark it makes. Lay it quietly on another spot of the table, and compare the marks.

12. When a ball is allowed to fall on a hard floor, there is a compression of the molecules of the ball near the point of contact with the floor. The elasticity of the ball causes an immediate restoration to the original form of the ball, and this produces the rebound. When gases are compressed, they recover their former state immediately when the pressure is withdrawn. They are said to be perfectly elastic. Although liquids can be compressed but slightly, they are also perfectly elastic.

Gases exhibit elasticity only on being compressed. Liquids and most elastic solids exhibit it when released from any kind of strain, though some highly elastic bodies can be *stretched* very little; *e.g.*, cold glass, steel.

Query.—What substance is uppermost in your minds as highly elastic when compressed, stretched, bent, or twisted?

13. **Limit of Elasticity.**—As stated above, there appears to be no limit to the elasticity of gases and liquids. Solids reach the limit of their elasticity when the molecules are forced so far from their position that they cannot regain it, and the body remains bent or compressed; or when they actually let go and the body breaks.

Mention some substances to illustrate each limit.

14. **Tenacity.**—When a solid is composed of molecules which adhere so closely that they strongly resist a force tending to pull them apart, it is said to be *tenacious*. The amount of tenacity depends on the structure of the substance. Wrought iron, being fibrous, has much more tenacity than cast iron, which is granular. Steel is very tenacious. A bundle of wires will support much more weight than the same material in solid form. Hence the cables of suspension-bridges, which have to hold up immense weights, are usually made up of bundles of fine steel wire.

If a piece of stick be placed on two supports some distance apart, and broken by a weight applied in the middle, the lower fibres will be found to be separated.

15. **Bridges.**—When a weight rests on a bridge, it has to stand the same kind of strain as the stick. The tendency is to pull it apart at the bottom. Hence an iron bridge has its lower "chord" made of tenacious wrought iron rather than of cast iron The upper chord is compressed, and is frequently made of cast iron, which will withstand more compressing force than wrought iron will.

16. **Hardness.**—Hardness is a property of solid bodies, which enables them to resist attempts to cut or scratch them.

Experiment 5.—Scratch a piece of glass with the edge of a quartz crystal or piece of flint. Attempt to do the same with a penknife-blade. Quartz is harder than glass, and glass is harder than the knife.

17. **Density.**—The density of a substance is the amount of matter in a given bulk. It is determined by the *weight* of the substance. A cubic inch of lead is heavier than a cubic inch of wood because it is more dense. Density is entirely distinct from hardness.

18. **Volume.**—The volume of a body is the amount of space it occupies, or its size.

19. **Mass.**—The mass of a body is the total quantity of matter which it contains. If a gas be heated it expands,

and the density decreases, but, as no new molecules are formed, the mass remains the same. The mass, therefore, depends on two things, volume and density. The number of molecules in a cubic inch of a body, multiplied by the number of cubic inches, gives the whole number of molecules. In other words, the product of the volume and the density gives the mass, or

$$\text{Mass} = \text{volume} \times \text{density}.$$

20. **Units.**—To designate masses, as indeed to designate length, area, volume, density, time, work, or anything else by number or definite quantity, we must refer in each case to a *unit*. A unit, when it is a measure of size or duration, is simply *one*. Other units are taken as one for *standards of comparison*. For instance, a given volume of hydrogen is lighter than the same volume of any other gas, therefore it is called one, and other gases are compared with it by number to denote their density, oxygen being 16, nitrogen 14, and so on.

21. **Two Systems of Units.**—Most of the countries of Europe have adopted a system of measures and weights which originated in France nearly a hundred years ago. In this system the number of one denomination required to make one of the next higher is always *ten*. As our *numbers* are formed in the same way (units, tens, hundreds, etc.) there is no reduction required when we use this system. It is known as the French or *decimal* system of weights and measures. The use of this system was authorized in this country by act of Congress in 1866, but it was not made compulsory, so in trade we still generally use the old system, which came from England and is still in use there, and which is known as the English system.

22. In this book both systems are used, the English because most boys and girls are more familiar with it, and the decimal, because it is much easier to calculate in, and because it is desirable that it should become familiar to us, so that we may adopt it.

23. Unit of Length.—The English unit of length is the *yard.* We may use the divisions and multiples of the yard —feet, inches, miles, etc.—in certain cases, and they become the units in those cases. The decimal unit of length is the *metre.* Remember that a metre is about 1 yard $3\frac{3}{8}$ inches, a decimetre about 4 inches, and a centimetre about $\frac{2}{5}$ of an inch. (See Appendix.)

24. The standard yard is a metal rod preserved in the Royal Exchequer, London. Other yard-sticks are as nearly the length of that one as they can be made. The standard metre is a metal rod preserved by the government of France. It is intended to be one forty-millionth of the meridian circumference of the earth.

25. Units of Surface and Volume.—The units of surface are simply the *squares* of the units of length, and the units of volume the *cubes* of the units of length. For instance, square foot, square yard, square metre; cubic foot, cubic yard, cubic metre. The square decametre and cubic metre take new names, as units, the square decametre being an *are* and the cubic metre being a *stere.* (Pronounced air and stair.) The cubic decimetre is the *litre* (leeter), and is the unit of volume for liquids, grain, etc.

26. Unit of Mass.—The English unit of mass is the avoirdupois *pound.* The French unit is the *gram*, which is the mass of a cubic centimetre of water at its greatest density. The pound is simply a standard weight of metal preserved in the Royal Exchequer.

27. The C. G. S. System.—The decimal system of units is generally designated in more advanced books as the "C. G. S." system, from the units of length, mass, and time,—centimetre, gram, second.

28. Unit of Density.—The unit of density for solids and liquids is the density of water at 39.2° F.

29. Affinity, Cohesion, Attraction.—The force which holds together the atoms in a molecule is called *affinity.*

The force which holds together the molecules in a body is called *cohesion.*

The force which holds together the different bodies of the universe is called *attraction.*

Hence affinity makes *substances;* cohesion makes *bodies;* attraction makes *systems.*

Attraction is also used to express the force which draws one body to another, as in the case of magnets, etc.

30. **States of Matter.**—There are three states or conditions of matter,—solid, liquid, and gaseous. A possible fourth state of matter is referred to in Arts. 45 and 570.

31. **Solids.**—In *solids* the molecules preserve their positions with considerable firmness, resisting attempts to displace them. Hence these retain their form and size. The force of cohesion is strong.

32. **Liquids.**—In *liquids* there is perfect freedom of the molecules among themselves, so that the bodies adapt their form to the surrounding vessel. They retain their size, but change their form with the slightest force exerted upon them. The force of cohesion is weak.

33. **Gases.**—In *gases* there is no cohesion, the molecules have a *repellent* action upon one another, so that an unrestrained gas will expand indefinitely.

34. **Motion of Molecules.**—The molecules of all bodies are believed to be in rapid motion. In solids this is restrained by cohesion, so that a molecule has only a short vibratory motion. In liquids the molecules slide over one another without resistance, restrained only when they reach the sides of the enclosing vessel. This contact produces the pressure against the sides. In gases the molecules are strongly repelled from one another, and dash about with great velocity. Hence there are constant collisions among them and with other bodies. Our bodies are subject to this incessant battering by the little molecules of the atmosphere, but, the force being the same on both sides of the tissues, we do not notice it.

35. **Adhesion.**—Adhesion is the force with which different surfaces stick together. It is adhesion which causes mortar to stick to bricks, paste to stick to paper, glue to wood, or two glued surfaces to stick to each other.

36. **Gravity and Weight.**—Unsupported bodies fall towards the earth. This is on account of the earth's attraction for them. Bodies that are supported press downward on account of the same attraction. The greater the attraction the harder the pressure. The *weight* of a body is simply the measure of the earth's attraction for it.

37. **Weight Proportional to Mass.**—The earth attracts or pulls every particle of a body. Suppose the pull of the earth on each particle to be exerted through a string attached to the particle, and suppose all the strings to be pulled together, the sum of all the pulls would represent the attraction on the whole body. Hence the more molecules the greater the attraction. But the mass is determined by the number of molecules. Hence we have the law,—

Under the same conditions the weights of bodies are proportioned to their masses.

38. **Unit of Weight.**—The unit of weight is the same as the unit of mass, the pound or the gram.

39. **How Gravitation Acts.**—The earth's attraction for bodies on or near it has been called gravity. In a wider sense, applied to the universe, it is called gravitation. This force is in many ways different from other forces. It does not require any time to act, nor does it require any medium to act through. It traverses the great space between the sun and the earth, to the best of our knowledge, instantaneously. Nor does the interposition of another body affect it in any way. We can cut off sound, or heat, or light, by the interposition of a wall, but attraction acts through it without diminution. Nor does the kind of matter make any difference. Every molecule is attracted alike, the number of molecules determining the total attraction.

40. **Law of Gravitation.**—The main facts of gravitation were discovered by Sir Isaac Newton, who announced th following law: *Every particle of matter in the universe a*

tracts every other particle, the attraction of any two for each other being directly proportional to the product of their masses, and inversely proportional to the square of the distance between them.

Questions.—How much is the attraction between two bodies increased by doubling the mass of one of them? By doubling the mass of both? How is attraction affected by doubling the distance between two bodies? By doubling both masses and doubling the distance between them?

41. **Gravity Above and Below the Earth's Surface.**—Gravity is greatest at the surface of the earth. When we go down into the earth gravity decreases, because some of the matter of the earth is attracting us upward. Were we to get half-way to the centre we should have only half the weight that we have at the surface. At the centre we should have no weight, being equally attracted in all directions.

As we go above the earth gravity decreases as the square of the distance from the centre of the earth increases.

42. **Mass Constant.**—The position of the body does not affect the *mass.* It might be removed far from the earth and the mass would be the same. The number of molecules—*i.e.*, the mass—would be constant if carried to the sun; but as there is so much more mass in the sun than in the earth, the attraction, and consequently the weight of the body, would be greatly increased.

43. **Mobility and Inertia.**—Bodies will not move unless some force is exerted on them from without, and they yield to the slightest force impressed which is not counterbalanced by some other force. This brings us to two other properties of matter,—*mobility*, which induces it to yield freely to impressed forces, and *inertia*, which prevents it from *moving* itself, from *stopping* itself, or from *changing its direction* of motion.

Examples of inertia are numerous. It requires more force to start a car than to keep it in motion. When sud-

denly stopped by another force, the contents are thrown forward by their inertia. A ball projected upward stops, not because it has power to stop itself, but because another force, gravity, is constantly pulling against its motion. A marble thrown swiftly through a pane of glass will make a small round hole, because the inertia of the other parts of the glass prevents them from yielding to the sudden impression.

Experiment 6.—Place a card on the end of a finger, and a cent on the card. By a quick stroke with the forefinger of the other hand the card may be shot out, leaving the cent resting on the finger.

44. **Ether.**—We have spoken of the three forms of matter, solid, liquid, and gaseous; we have also said that the molecules of matter do not fill up the whole space, but that pores, which are large compared with the size of the molecules themselves, exist in all substances. This intermolecular space is supposed to be filled with something called *ether*, which is as far separated from gases by its properties as gases are from liquids. It also fills the pores of the air, and the spaces between the planets and between the stars, outside the bounds of the atmospheres which surround them. It is highly elastic, without weight or color, or any other properties which can be perceived by the senses. It is supposed to be the agent which by its vibratory motion conveys the rays of light from the sun to the earth, and which carries them between the molecules through transparent substances.

45. **Radiant Matter.**—Dr. William Crookes[1] has found that by exhausting the air in a tube so as to leave not more than one-millionth the ordinary amount, the remaining substance has properties so peculiar that he feels justified in giving it a new name. He calls it *radiant matter*, and considers it to be a fourth form of matter. Solid, liquid, gaseous, and radiant would then be the four aggregate

[1] An English scientist, now living (1892).

states, each having properties which widely separate it from the others. By passing electric sparks through radiant matter some of its properties have been determined.[1]

Exercises.—1. Is matter destroyed when water is dried up? when gunpowder explodes? when house gas burns? Where does it go to?

2. To what property of matter do blotting-pads owe their utility? rubber bands? watch-springs? pop-guns? putty? hammers? piano-strings? water-filters?

3. Why does not the addition of a little sugar to a full cup of coffee cause it to overflow?

4. When we fix the head of a hammer on the handle by striking the end of the handle on a block, what property do we use?

5. Why does a foot-ball, nearly empty, become full when we exhaust the air from around it? why does it soon collapse?

6. One sixteen-thousandth of a cubic inch of indigo dissolved in sulphuric acid can color two gallons of water. What property of matter is here shown?

7. How would you test the relative hardness of two minerals?

8. When water is converted into steam, are the molecules enlarged or separated? is its mass increased or diminished? its density? its weight? its volume?

9. Name a substance which is often found in all three forms.

10. If you knew the volume and mass of a solid, how would you obtain its density? if you knew its mass and density, how would you obtain its volume?

11. Give an instance of a hard body which has little cohesion.

12. Why does not a large stone fall to the earth more rapidly than a small one?

13. If a body were removed to a distance of 8000 miles from the surface of the earth, how much less would it weigh than at the surface? *Ans.* $\frac{1}{4}$ as much.

14. What would a 100-pound weight weigh if moved to the distance of the moon (60 radii of the earth)? *Ans.* $\frac{1}{36}$ pound.

15. Suppose a sphere were one-half the diameter of the earth and of the same density, what would a body which weighed 100 pounds on the earth weigh at its surface? *Ans.* 50 pounds.

Note.—Its mass would be one-eighth that of the earth, and distance of the body from its centre one-half.

SUMMARY OF CHAPTER I.

46. **Matter** is made up of a countless number of minute molecules. It is perfectly inert, but each particle has the property of attracting every other particle.

It has extension in three dimensions. It has three (possibly four) states of aggregation.

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[1] *These will be* further explained, page 330.

CHAPTER II.

MOTION AND FORCE.

47. **Rest and Motion.**—In natural philosophy we generally speak of *motion* with reference to fixed points on the earth, and these are said to be at *rest*, though of course they are moving with the earth through space. We may consider motion with reference to any other point. A man moves in a boat when he shifts on his seat, or in a moving train when he walks from one part of the train to another.

48. **Kinds of Motion.**—When a body in motion passes over equal spaces in equal times, its motion is *uniform*. When it passes over unequal spaces in equal times, its motion is *varied*. When the spaces in successive times become greater, its motion is *accelerated*, and when less, *retarded*. This acceleration or retardation may also be uniform or varied.

49. **Velocity.**—The *velocity* of a motion is the space traversed in a unit of time. It may be in miles per hour, feet per second, etc.

Feet moved in Successive Seconds.				Kinds of Motion.
30	30	30	30	Uniform.
10	15	20	25	Uniformly accelerated.
20	18	16	14	Uniformly retarded.
20	14	16	4	Varied,—not uniformly.

Questions.—When a train starts from a station, what kind of motion is it? when stopping? when a ball is thrown upward? when it falls? What kind of motion in the hands of a watch? in the current of a river? in the winds?

50. Force.—*Force is anything which tends to produce, change, or destroy motion.* One force on a body at rest tends to move it. If it acts on a body in motion, it may change the direction or velocity of the motion, or destroy it. Two or more forces may act on a body at rest so as to balance each other and cause no motion. But each one *tends* to produce motion. In bridges and buildings we have cases of balanced forces. Gravity is a force always acting upon them, and upon everything they sustain. This produces other forces acting along the various timbers and pieces. If the structure is well built, the strains from these forces are exactly balanced, every part is sufficiently strong to do its work, and there is no motion except such as is due to the elasticity of the materials.

51. Kinds of Force.—A force may act for an instant and then cease, in which case it is said to be an *impulsive* force; or it may act for some time, when it is a *continuous* force. The striking of a ball by a bat is an example of an impulsive force, and the pulling of a train by a locomotive, of a continuous force.

52. Impulsive Force produces Uniform Motion.—*An impulsive force tends to produce uniform motion, and a continuous force accelerated motion.* This would seem to be contradicted by experience. For the motion of a ball is soon destroyed, and the continual pull of the engine may only keep the train moving uniformly. But the force of the bat or of the locomotive does not act alone. Were it not for gravity, the resistance of the air, and friction, which are modifying forces, the ball would move on forever with uniform velocity, and the velocity of the train would be accelerated so long as the engine pulled it ever so slightly.

53. Newton's Laws of Motion.—All the circumstances of motion are embraced in three laws, first enunciated by Sir Isaac Newton. These cannot be proved mathematically. They should be looked upon as fundamental prin-

ciples, which depend on the properties of matter, and which may be shown to be true by experiment.

They are as follows:

1. *A body at rest remains at rest unless acted on by a force; and a body in motion would move forever in a straight line with uniform velocity unless acted on by a force.*

2. *Motion, or change of motion, is proportional to the force impressed, and is in the direction in which the force acts.*

3. *For every action there is a reaction equal in amount and opposite in direction.*

54. The first law is the result of the inertia of matter, and the second, of its mobility. The first says matter can do nothing itself, and the second, that the slightest force will have its corresponding effect.

The third law may be made clear by some illustrations. The earth attracts an apple and causes it to fall. The apple attracts the earth just as strongly, and the earth moves to meet it, but the greater mass of the earth makes it move so little that the motion is not noticed. A horse walking on a tow-path pulls a loaded canal-boat. He acts, through the rope, on the boat, and the reaction occurs where his feet press backward against the ground. Put the horse on the forward deck and let him pull ever so hard on the same rope shortened, he could not move the boat, because both action and reaction would be exerted on it, and would balance each other.

55. **Momentum.**—*Momentum is the quantity of motion.* The momentum of the earth *was the same as the momentum of the apple.* For while its *velocity* was less, its *mass* was as many times greater. Hence mass and velocity together make up momentum. A body weighing two pounds has twice the motion of one of one pound which has the same velocity; a body with twice the velocity of another has twice the motion, the mass being the same. In general we have the equation,—

$$\text{Momentum} = \text{mass} \times \text{velocity}.$$

56. The number representing the momentum of a moving body has no name, and such numbers are used only in comparing. A body weighing 200 pounds and moving 10 feet per second (momentum 2000) has twice the momentum—that is, twice the moving power—of a body weighing 50 pounds and moving 20 feet per second (momentum 1000). In the case of action and reaction between two moving bodies, or bodies free to move towards each other, the momentum of one is equal to the momentum of the other.

Questions.—A man standing in the bow of a boat which, with its load, weighs 500 pounds, pulls on a rope which extends to a man standing in the bow of a similar boat weighing 1000 pounds. How do the momenta of the boats compare? How do their velocities compare?

57. **Measure of Forces.**—We may measure forces in two ways. One way is by the pressure necessary to resist them,—*weighing* the forces, as it were. The unit is then the pound or the gram. These vary as gravity varies, being greater nearer the level of the sea. A better way to measure forces is by the velocity they would produce if acting alone. The velocity which a force can impart to a unit of mass by acting on it for a unit of time is its *acceleration.*

58. **Units of Force.**—In the English system the units are the pound and second, and the unit of force is that force which in one second will give a mass of one pound a velocity of one foot a second. The C. G. S. system employs the C. G. S. units (Art. 27), and gives us the unit of force called the *dyne*, which means force. The dyne is the force which, acting for one second, will give a mass of one gram a velocity of one centimetre a second, *i. e.*, which will give one gram an acceleration of one centimetre per second.

59. If a force of a dyne act constantly on a moving mass of one gram, it will increase its velocity regularly, for at the end of each second the inertia keeps it moving at its acquired velocity, and the force *adds* to its velocity continually. The additional velocity in any mass is directly proportional to the force; hence the *acceleration is a measure of the force.*

60. **Magnitude of the Units of Force.**—The units of force must not in any way be confounded with the units of weight which

are named in defining them. The *weight* of a pound or of a gram is a measure of gravity. Now, gravity acting on any ordinary mass of matter near the earth and free to fall, gives it an acceleration of about 32.2 feet, or 980 centimetres per second. (See Art. 88.) If the mass is a gram, and it acquires a velocity of 980 centimetres a second, it must be acted upon by a force of 980 dynes, as one dyne could give it a velocity of only one centimetre per second. The dyne is equivalent, then, to a force or pressure of $\frac{1}{980}$ of a gram at the sea-level. The *megadyne* (million dynes) is used in practice to denote forces of appreciable magnitude.

61. **Effect of Two Forces.**—Experiment 7.—Fasten two pulleys against a vertical board so that they will turn freely. Arrange cords as in the figure, making the knot at *a* so as not to slip. Hang weights *p*, *q*, and *r*, being careful not to get *r* greater than *p* and *q* combined. Measure *ab* and *ac*, proportional to the weights *p* and *q*; that is, if *p* is three pounds, make *ab* three feet, and if *q* is four pounds, make *ac* four feet. Make the string *bdc* seven feet long, and fasten it at *b* and *c*. Put a pin at *d*, four feet from *b* and three feet from *c*. Hang a plumb-line from this pin. It will pass the point *a* and the weight *r*, and the distance *da* will be as many feet as there are pounds in *r*.

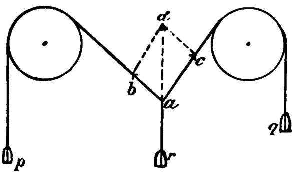

FIG. 2.—PARALLELOGRAM OF FORCES.

62. **Parallelogram of Forces.** — The figure *abdc* is a *parallelogram*, and the line *da* is the *diagonal*. Any two forces acting on a body in the same plane, but not in the same straight line, move the body from one corner to the opposite corner of a parallelogram, just as the forces *p* and *q* suspend the weight *r* in the direction of the diagonal. This is illustrated in rowing a boat *across* a current, and in many other familiar ways. Draw two lines to represent the direction and magnitude of the forces. Through the end of each of these lines draw a line parallel to the other. The figure will be the parallelogram of forces, and the

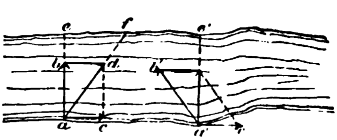

FIG. 3.—CROSSING A CURRENT.

diagonal, which represents the direction and distance taken by the body, is the *resultant* of the two forces. In Figs. 2 and 3, *ad* is the resultant of *ab* and *ac*. So any number of forces may have one resultant.

63. **Centrifugal Force.**—When a body is swung around by a string there are two forces acting on it. One is its inertia, which would tend to make it move in a line, *ab*, touching the curve. The other is *ac*, the pull of the string. The tendency would be to move in the diagonal *ad*. But as this pull is acting continuously, and the direction continually changing, the line is a curve. These are the forces which keep the earth and all the planets in their orbits.

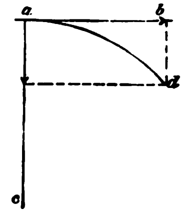

FIG. 4.—MOTION IN A CURVE.

The outward pull on a string, which is the result of the


FIG. 5.—CENTRIFUGAL FORCE APPARATUS.

inertia of the body tending to cause it to get farther from the centre, is *centrifugal force*. It is always equal to the

force drawing towards the centre and opposite in direction.

64. **Effects of Centrifugal Force.**—A striking effect of centrifugal force is shown by the apparatus of Fig. 4. Here the flexible bands are put in rapid rotation, and the centrifugal force makes them assume the form indicated by the dotted line. When the earth was a soft body, the centrifugal force caused by its rotation on its axis probably produced the bulging at the equator which we now notice. The centrifugal force is greater at the equator than elsewhere, because of the greater velocity of the earth there. Hence bodies are lighter there than at the poles. An equestrian leans inward in riding around a curve, to balance the centrifugal force. It is this force which causes mud to fly from moving carriage-wheels, or water from a grindstone, and which sometimes breaks a rapidly-revolving fly-wheel. In sugar-refineries the syrup is separated from the crystals by being thrown outward, the sugar being retained by a wire gauze. Clothes are dried by a similar arrangement. In a bicycle in motion the centrifugal force causes the particles to continue to move in the same plane. Hence the faster it is going the more difficult it is to overturn.

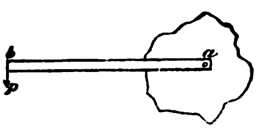

FIG. 6.—MOMENT OF A FORCE.

65. **Moment of a Force.**—The moment of a force is its ability to produce rotation. If *ab*, Fig. 6, be a lever rotating about the point *a*, and a force *p* be applied at *b*, in the direction of the arrow-head, it will, if sufficient, turn the body. This ability will depend on the magnitude of the force and the length of its lever-arm, and is equal to their product. Thus, the moment of $p = p \times ab$.

Exercises.—1. A force of ten pounds has a lever-arm of 2 feet: what is its moment?

Ans.—20 foot-pounds.

2. A force of 16 grams has a lever-arm of 200 metres: what is its moment in kilogram-metres?

66. Work.—Work consists in moving against resistance. A horse or an engine does work when it pulls a load, a bird when it propels itself through the air, a man when he lifts up a weight.

Let us take the latter case. When a load is lifted, a certain amount of work is done; when it is lifted twice as high, twice as much work is done, or when the weight is twice as great, twice as much work is done; when twice as great a weight is lifted through three times the height, six times the work is done; or,

$$\text{Work done} = \text{weight} \times \text{height}.$$

In general, the work done by any force is the product of the force and the distance through which it moves.

67. Unit of Work.—The unit of work in the English system is the *foot-pound.* It is the work done in lifting the unit of weight (pound) through a unit of height (foot). The French system uses the units kilogram and metre, and the unit of work is the *kilogram-metre.*

68. Power.—When *work*, simply, is estimated, the *time* required for it is not taken into account. Ten pounds lifted 10 feet are 100 foot-pounds of work, whether hoisted by an engine in a second or carried up a ladder by a boy in a minute. But it is evident that when *power* is estimated time must be taken into account. An engine which will perform 1000 units of work in a second has twice the power of an engine which requires two seconds to perform the same work.

69. Unit of Power.—The unit used in estimating the power of engines, boilers, electric motors, water-wheels, etc., is the *horse-power*, which is the ability to do 33,000 foot-pounds of work in one minute. To find the horse-power of an engine, multiply the weight lifted, or pressure of steam in pounds, by the number of feet moved in one minute, and divide by 33,000. An engine having a piston of 165 square inches, a two-foot stroke, and an average available steam-pressure of 25 pounds per square inch,

develops 75 horse-power when making 150 revolutions per minute.

Exercises.—1. Work out the above.

2. How many foot-pounds of work are done in lifting 20 pounds 10 feet?

3. An engine hoists 2 tons of coal up a 600-foot shaft in 1 minute: what horse-power does it exert?

4. What horse-power is required to perform the work of the last example in 2 minutes? in 5 minutes? in ½ minute?

ENERGY.

70. **Energy is Ability to do Work.** A moving body has energy. A body lifted up has energy. They can do work in moving or in falling. The units of energy are the same as the units of work.

71. **The Erg.**—The units of work given in Art. 67 are derived from the *weight* of the pound and the kilogram. Weight depends upon gravity, and as this varies with the distance from the earth's centre, any units derived from it must vary accordingly. This variation on the earth's surface is very slight, and the units are likely to remain in use when estimating heavy work. For the purpose of exact science, however, an *invariable* unit of energy is desirable. The *erg* is such a unit. It is the energy expended or the work done by a force of one dyne (Art. 58) acting through one centimetre.

This is equivalent to lifting $\frac{1}{981}$ of a gram, at the sea-level, 1 centimetre high. (Art. 60.)

How many ergs in a kilogram metre?

72. The dyne and the erg are invariable, because they depend upon the *mass*, not the *weight*, of a cubic centimetre of water.

73. **Potential Energy.** A weight held up by the hand has the power by virtue of its position to fall, and hence do work, if its support be withdrawn. A body of water held up by a dam has the power to do work on a water-wheel, if allowed to fall upon it. A wound up spring has power to perform work in turning the machinery of a clock.

The ability to do work which a body thus has by reason of its position is called *energy of position*, or *potential energy.*

74. **Kinetic Energy.**—A weight descending, water falling on a wheel, a spring uncoiling, a bullet moving through the air, a muscle in use, have energy,—*energy of motion*, or *kinetic* energy, sometimes called *actual energy.*

75. The formula for potential energy is $w \times h$, where w represents the weight of a body, and h the height to which it is raised.

76. **Potential and Kinetic Energy Equal.**—If the body w falls the distance h, it can of course raise a corresponding weight to the same height; that is, its kinetic energy is equal to $w \times$ distance it falls, which is the same as $w \times h$.

77. **Transformation of Energy.**—When a body is thrown upward its energy of motion becomes less and less. When it has reached its greatest height this has been all converted into energy of position. As the body falls the energy of position reappears as energy of motion, and when the body strikes the ground the kinetic energy is equal to the potential energy at the highest point.

78. **Conservation of Energy.**—Energy is indestructible as matter is, though it is frequently changed in form. The heat of a steam-engine is converted into motion, and the motion, carried to a dynamo, is converted into electricity, which may be converted into light or into heat again. So with every form of energy, none of it can be completely destroyed any more than matter can. This great principle is known as the *conservation of energy*, and in its fullest sense it means that the *total energy of the universe is always constant in quantity*, never more, never less, no matter what variations it passes through. When a moving object comes to rest without doing manifest work, its energy is simply transferred to something else, to motion of the air, heat of brakes, bearings, &c.

Experiment 8.—Place about a half-dozen glass "marbles," or better, ivory balls, over a crack between two smooth, level floor-boards. See

that they are all in contact. Draw back the ball at one end and roll it against the end of the line. The ball at the other end will move away, and the others will maintain their places. How did the energy pass through the middle balls without moving them?

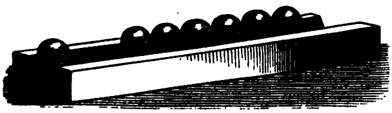

FIG. 7.—COLLISION BALLS.

Experiment 9.—Stretch a string, not too tightly, between two supports several feet apart. Suspend from it, at equal distances from the ends, by equal strings, two equal weights, *a* and *b*, Fig. 8. Draw the weight *b* back, so that it will swing *across* the direction of the horizontal string. Soon *a* will begin to swing, and when it has attained the length of swing originally given to *b*, *b* will be noticed at rest. Immediately, however, *b* starts to swing again, and, on attaining its original height, *a* will be found at rest. So they alternately swing and rest for some time, the friction of the air, etc., finally stopping them. Notice that the original energy of position given to *b* was sufficient to carry either *a* or *b* alone to the full height, or both together to half the height, but never to carry both together to the full height at which *b* started. This is a very entertaining experiment.

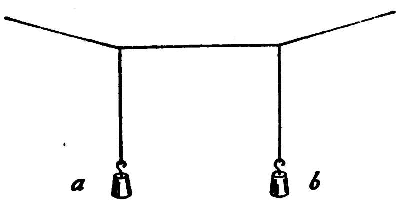

FIG. 8.—CONSERVATION OF ENERGY.

CENTRE OF GRAVITY.

79. **Definition.**—The centre of gravity of a body is the point on which it will balance. If a body has a regular shape and a uniform structure, the centre of gravity is in the middle.

80. **To Find the Centre of Gravity.**—The centre of gravity of an irregular board, or other thin body, may be found as follows: Suspend the body freely on a round awl thrust through it at any point, and suspend a plumb-line from the awl at the same time. The centre of gravity will hang directly *below* the point of support; that is, somewhere in the plumb-line. When the body and the plumb-line come to rest, clasp the line to the body, and mark its path with a pencil and ruler. Now thrust the awl through any

other point of the body and suspend the plumb-line as before. The centre of gravity will be in the plumb-line again, and as it is in both plumb-lines, it is at their intersection. Bore a hole here, and the body will revolve freely on the awl. In the case of most irregular solids the centre of gravity is calculated from the shape of the body and weight of the parts.

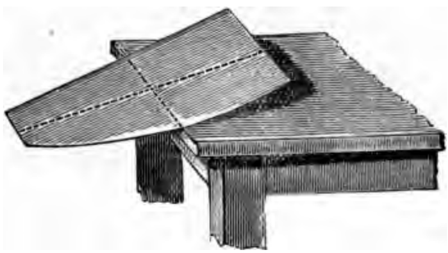

FIG. 9.—CENTRE OF GRAVITY.

Experiment 10.—Lay a thin board on the edge of a table, and when it is just ready to fall, mark the table-edge with a pencil. Change the position of the board, and again mark the table-edge. Bore a hole at the intersection of these lines and insert an awl to rotate the board on.

81. **Line of Direction.**—The line of direction is a vertical or perpendicular line through the centre of gravity of a body.

82. **Stability.**—A body so supported that the centre of gravity is *raised* by any attempt to overturn the body is *stable.* If the centre of gravity begins immediately to *fall* the body is unstable. Example of a stable body, a brick lying flat; of an unstable body, an egg balanced on end.

83. **Base and Stability.**—If the line of direction fall within the base of support of a body, the body will stand, otherwise it will overturn. The larger a body's base the more stable it is, for the line of direction will have more room for play when the body is tilted. The higher a body the less stable it is, for the centre of gravity swings faster

when the body is tilted, and soon brings the line of direction outside the base.

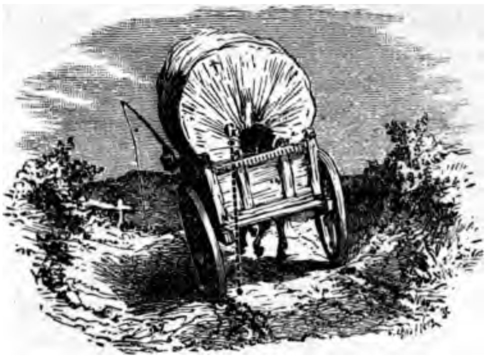

Fig. 10.—Line from Centre of Gravity must fall inside the Wheels.

Queries.—What would be the effect of building the tower of Pisa[1] considerably higher?

What is the general shape of very high chimneys, and why?

A farmer hauls loads of hay and loads of stone over the same slanting road: which is more likely to upset?

84. When a man stands erect, the line from his centre of gravity falls between his feet. In beginning to walk, he throws his body forward, so as to bring his centre of gravity in front of his feet. He would now fall did he not catch himself by throwing one foot forward. The operation is then repeated with the other foot. He also throws his body from side to side, so as to keep the centre of gravity over the foot which is on the ground. In carrying a weight on his back he leans forward, and in carrying it in one hand he leans sidewise for the same reason.

85. **The Bicycle.**—The bicycle has no base, and therefore it is entirely unstable; that is, it will not *stand*. When running, the rider moves his centre of gravity slightly from side to side, and also by slightly turning his wheel in

[1] Where is this, and how constructed?

the direction in which he tends to fall, he makes use of centrifugal force to straighten up his machine.

86. **Suspended Bodies.**—When a body is freely suspended the centre of gravity is always under the support (Art. 80), and of course it is always stable.

Experiment 11.—Construct the apparatus shown in Fig. 11. *ab* and *bc* are two pine sticks notched together, or hinged together, at *b*. *cd* is a string tied to the handle of the pail and fitting into a notch at *d*. Have the pail part full of corn.

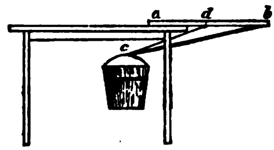

Fig. 11.

Experiment 12.—Bend a piece of rather stout wire into this shape, and fasten an ounce or two of lead to each end. Then place the end of the tongue *T* on the corner of a table, so that the weights will not touch the table. On trial, bend the tongue a little, if necessary, so that the frame and weights will rest level.

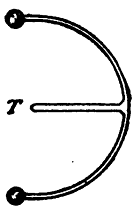

Fig. 12.—Centre of Gravity.

Experiment 13.—Thrust a needle with a sharp point up through a cork, and put the cork in a bottle. Into another cork thrust a pin and two knives or forks. The side of the pin may now be supported on the point of the needle, and the forks set to revolving, best by *blowing* on them.

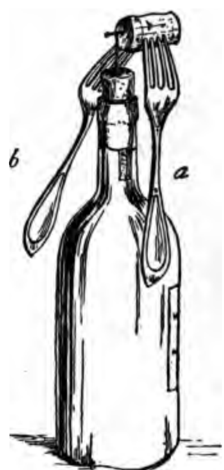

Fig. 13.

87. **Bodies Revolve about the Centre of Gravity.**—**Experiment 14.**—Make a ball of wood or cork and firmly imbed a heavy piece of lead in one side of the ball. Throw the ball up into the air with a twirling motion. Try rolling it across the floor.

Any revolving body, or system of revolving bodies, revolves about the *common* centre of gravity. We say the

earth revolves about the sun. They both revolve about their common centre of gravity, or the point at which they would balance if placed on opposite ends of a lever. (Art. 103.)

Exercises.—1. When will a body slide, and when roll, down an inclined plane?

2. In rising from a chair, why do we lean the body forward?

3. Why is it easier to walk on a fence with a long stick in the hand?

4. When is a pendulum in stable equilibrium?

5. Is a cone balanced on its apex stable? on its base? on its side?

6. Why cannot a person pick up an object from the floor in front of him when standing with his heels against a vertical wall?

7. Should the centre of gravity of a ship be high or low? of a wagon?

8. Why is it easier to suspend an iron ring on a nail on the inside than to balance it on the outside?

9. What would a 200-pound man weigh if moved to within 1000 miles of the centre of the earth? *Ans.* 50 pounds.

FALLING BODIES.

88. **Acceleration of a Falling Body.**—We have learned (Art. 57) that acceleration is a measure of a force. This applies especially to *gravity*, because it acts on a body uniformly—with uniform pressure or stress—no matter in what direction or at what rate it may be moving. Other forces frequently lose in intensity, as the velocity of motion increases, in the direction in which the force acts. This effect of gravity is shown in a body falling towards the earth,—the *centre* of the earth. It is found, by experiment, that a body falling freely towards the earth increases its velocity at the rate of 32.2 feet (9.80 metres) per second. In algebraic equations for solving problems relating to falling bodies this quantity (32.2 feet, or 9.80 metres) is represented by the letter g.

89. It may be asked, Why does acceleration measure the force of gravity more accurately than *weight*, which is the constant pull of gravity on a body at rest? Weight depends upon mass (Art. 37), and as the masses of different bodies are not the same, it is plain that we can derive from this nothing uniform to represent the pull of gravity.

All bodies, small and large, *fall towards the earth with the same velocity*, so that this gives us a uniform standard of attraction.

Some of the old philosophers thought and taught that the rate of a falling body was dependent upon its mass. They did not try the experiment, as any boy or girl may, by letting a dime and a half-dollar drop to the floor at the same instant. The half-dollar is pulled five times as hard as the dime is, and they would have reasoned that therefore it should move five times as fast. They did not consider that the fivefold force has *five times the mass to move.* Suppose we were to let six dimes drop. We should expect them to strike the floor at the same instant. What difference can it make if five of them are joined together in a half-dollar?

90. **Time and Distance of Falling Bodies.**—Having learned by experiment the acceleration caused by gravity, we can easily apply it to finding the distance a body falls in a given time, the time required to fall a given distance, etc. Let us give an illustration:

First, it will be readily granted that as gravity increases the rate of a falling body by 32.2 feet per second, the velocity (represented by v) is always equal to 32.2 feet multiplied by the number of seconds the body has been falling (represented by t, for *time*), or $v = gt$.

Second, it is easily seen that if a body starts from rest and *increases its velocity uniformly* for any length of time, its velocity in the middle of the time will be *one-half* the velocity at the end of the time, or its *average* velocity is one-half its final velocity, or $\frac{1}{2} gt$. This average velocity multiplied by the number of seconds must give the whole space traversed by the body (represented by s), or $s = \frac{1}{2} gt \times t = \frac{1}{2} gt^2$. This equation gives us a direct method of finding times and distances mentioned above.

Note.—These problems may be solved arithmetically. Of course the space divided by $\frac{1}{2} g$ (16.1 feet, or 4.90 m.) will give the square of the time in seconds.

Exercises.—1. How far will a body fall in 5 seconds?
2. How far will a body fall in $6\frac{1}{2}$ seconds? *Ans.* 680.225 feet.
3. How many metres will a body fall in 2 seconds?

4. The upper suspension bridge at Niagara Falls is nearly 197.225 feet high: how long would it take a stone to drop from the bridge to the water?

Solution.—As $s = \frac{1}{2}g \times t^2$, $t^2 = s \div \frac{1}{2}g$. $197.225 \div 16.1 = 12.25$, this being t^2, $t = \sqrt{12.25} = 3.5$, number of seconds.

5. The Eiffel tower is 300 metres high: how long would it require for a cold chisel to drop from the top to the bottom. *Ans.* 7.82 seconds. With what velocity would it strike?

6. How high is a balloon when a bag of ballast thrown out requires 9 seconds to reach the earth? What velocity does the bag acquire?

91. **Projection Upward.**—When a body is projected upward, the attraction of the earth takes away from its energy of motion, and when it falls it gives it back again. It has the same velocity in coming down that it had in going up at the same height. The circumstances of the motion are just reversed.

Exercises.—1. A boy kicks a foot-ball straight up. It comes back again in 4 seconds. How high did it go? what velocity did he give it?

Suggestion.—The ball *rose* just half the time.

2. A bullet is shot upward with a velocity of 257.6 feet per second: how high will it go?

92. **Resistance of the Air.**—The figures and results given above make no allowance for the resistance of the air. On account of this resistance the velocity of bodies falling in the air is always less than the calculated velocity, heights are less than calculated heights, and times are longer than calculated times. The resistance of the air is greater for light bodies than for heavy ones, and it increases as velocity increases, but much more rapidly.

Experiment 15.—Carefully cut a piece of paper into a circular shape slightly smaller than a silver dollar. Hold one in each hand and let them drop at the same instant. Now place the paper disk, level, on top of the dollar, and let the dollar go. If carefully done, the dollar pushes the air away, keeps it from the paper, and they fall together.

93. If a body were projected horizontally from the top of a tower, it would reach the level at the same time as if it were dropped. Moreover, it would reach the level at the same time whatever its velocity of projection. For gravity

is the only downward force acting, and it pulls the ball to the earth in just the same time, whether it moves horizontally during the time or not.

Experiment 16.—Slide a coin or roll a marble with force from a level table so that it will shoot horizontally nearly across the room. Just as it leaves the table let another one *drop* to the floor. If accurately started, they will strike the floor at the same instant.

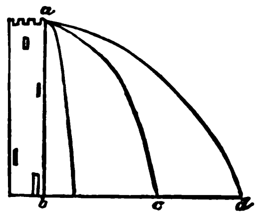

FIG. 14.—PROJECTION HORIZONTALLY.

94. Curved Path of a Projectile.—In the above experiments the projected body was acted upon by two forces, the projecting force and gravity. The projecting force was impulsive (Art. 51), but gravity acted continuously. The path was curved. All projectiles move in curved paths because they are acted upon continuously by gravity. It is a law, that *motion in a curve is always produced by the action of a continuous force directed toward a point out of the line of motion.* The grandest examples of this are seen in the motions of the heavenly bodies. The planets revolve around the sun, having received somehow an initial velocity, moving by inertia, and being *continuously* acted on by the sun's gravitation.

THE PENDULUM.

95. Definition.—A pendulum is a weight suspended by a cord or rod, so that it may swing back and forth. One swing of a pendulum is called a *vibration.* When drawn aside from a vertical line, the weight is raised and gravity causes it to descend. Its inertia carries it up the other side, and were it not for friction and the resistance of the air it would rise to the height from which it fell, and swing back and forth forever. On account of these resistances it does not rise so high, but makes shorter and shorter vibrations, and is finally brought to rest.

96. Energy of a Pendulum.—When drawn aside, it has energy of position equal to its weight multiplied by *ab*;

this is converted into energy of motion in the fall, and this is reconverted to energy of position in the ascent, except such portion of it as appears as heat in the point of suspension and in the air. Finally the whole energy is converted into heat, and the pendulum comes to rest.

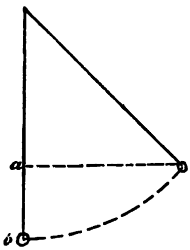

FIG. 15.—PENDULUM.

97. **Laws of the Pendulum.**—1. *The time of a given pendulum is independent of the extent of vibration.*

With the common pendulum, a long swing is performed in very nearly the same time that a short one is. A pendulum can be so arranged that the times will be exact.

2. *The times of different pendulums at the same place are proportional to the square roots of their lengths.*

The converse of this rule is useful in practice; the *lengths* are proportional to the *squares of the times.*

Note.—The length of a pendulum is taken from the point of suspension to the "centre of oscillation," a point near the centre of gravity of the weight.

3. *The times of the same pendulum at different places are inversely proportional to the square root of the intensity of gravity.*

98. This law gives us a means of determining the shape of the earth. A pendulum at the equator is made to beat seconds accurately. Taken to New York it beats more rapidly, showing that it is nearer the centre of the earth. (Art. 64.) Taken to Iceland it beats more rapidly yet, showing that it is still nearer the earth's centre.

Query.—How much nearer is the North Pole to the earth's centre than a point on the equator, both being at sea-level?

99. **The Seconds Pendulum.**—In the Middle United States a pendulum about 39.1 inches, or 993 millimetres,

long vibrates once a second, and is called the *seconds pendulum.*

Experiment 17.—(1st Law.) Suspend a weight of one or two ounces by a thin string to a nail driven into a wall. Slide the loop out on the nail, that the weight may not *rub.* Measure the string about 39.1 inches to the centre of gravity of the weight. Draw the weight aside a foot and let it swing. Take the time of 30 vibrations. Again take the time of 30 vibrations when the pendulum is swinging but a few inches.

Experiment 18.—(2d Law.) Suspend a second weight by a string one-fourth as long as the first. Draw aside and let both go at once. What result?

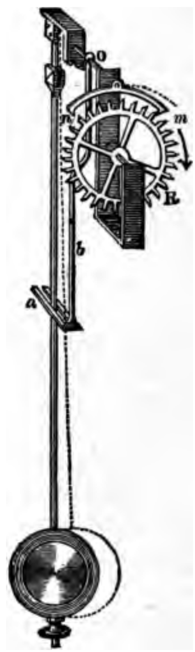

Fig. 16.—Pendulum for Clocks.

Exercises.—1. If a seconds pendulum in a given place is 39 inches long, how long is a pendulum that beats half seconds? how long to beat one-third seconds? how long to vibrate in two seconds? how long to vibrate in one minute?

2. Some experiments were recently made with a pendulum at Bunker Hill Monument. If the string was $208\frac{8}{15}$ feet long, what was the time of vibration? (See Art. 99.)

100. Pendulum for Clocks.—The use of the pendulum in clocks may be explained by Fig. 16. The pendulum swings between two arms *a*, and is connected with the rod *o* and the *escapement mn.* The *pallets* of the escapement work into the teeth of the *escapement-wheel R.* When the pendulum swings, one of the teeth of the wheel escapes from the pallet *m*, and the clock weight (or spring) which acts through the train of wheels falls a little and moves *R* forward. But no sooner has *m* released a tooth than *n* catches another, which cannot be released till the pendulum swings back and lifts *n* out. So the teeth are released just as rapidly as the pendulum swings. Heat and cold lengthen and shorten ordinary pendulum-rods, and thus change the rate of the clock. Many pendulums have mechanical devices by which the heat, while it lengthens the

rod, raises the weight, and *vice versa*, and thus keeps the pendulum of the same length. The hands and face of a clock are simply to keep count of the number of times the pendulum vibrates, and thus save us very monotonous work!

MACHINES.

101. **The Mechanical Powers.**—All machines, however complex, are combinations of one or more of the six *mechanical powers*,—viz., the *lever*, *wheel and axle*, *pulley*, *inclined plane*, *wedge*, and *screw*.

These six mechanical powers, and the many combinations of them in machinery, are intended, in a general sense, to increase either the efficiency of the power applied to the machine, or the rate of motion.

102. **Law of Machines.**—It is a universal law in mechanics that *power is gained only at the expense of speed, and speed is gained only at the expense of power.*

This follows from our definition of momentum. A heavy weight moving slowly has as much moving force as a light weight moving rapidly. In the mechanical powers we always consider a *weight* or *load* to be moved (or resistance to be overcome) and a *power* to do the work. In calculating the efficiency of a machine, the power and load are considered to be balanced, or in equilibrium. If the power *moves* the load, it must be greater than the amount calculated for equilibrium, and enough greater at least to overcome the friction of the machine and the inertia of the load.

THE LEVER.

103. **The Lever.**—A lever is any bar or rod which is used to pry or move a weight, by having the power applied to one point which is free to move, the weight supported on another movable part, and another point resting on or against an immovable support. This support is called the fulcrum, and there are three classes of levers, depending upon the position of the fulcrum.

In levers of the first class the fulcrum is between the power and the weight. (Fig. 17.)

FIG. 17.—LEVER OF THE FIRST CLASS.

In levers of the second class the weight is between the power and the fulcrum. (Fig. 18.)

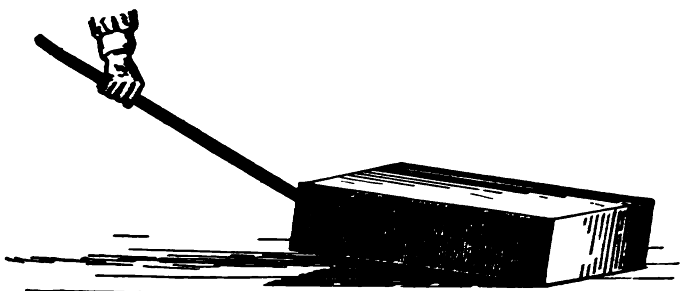

FIG. 18.—LEVER OF THE SECOND CLASS.

In levers of the third class the power is between the weight and the fulcrum. (Fig. 19.)

Questions.—What kind of lever is a balance? a see-saw? a pair of scissors? a ladder raised by a man near its base? the forearm of a man? a pair of tongs? pincers? a wheelbarrow? sheep-shears? the handle of a water-pump? a claw-hammer used in drawing a nail? the rudder of a ship?

Where is the fulcrum in each case?

104. Lever-Arms and Leverage.—The part of any lever between the power and the fulcrum is called the *power-arm*

of the lever, and the part between the weight and the fulcrum is called the *weight-arm*. *The ratio of the power-arm to the weight-arm is called the leverage, and represents how many times greater the weight is than the power*, or the number of times the power is multiplied by using the lever.

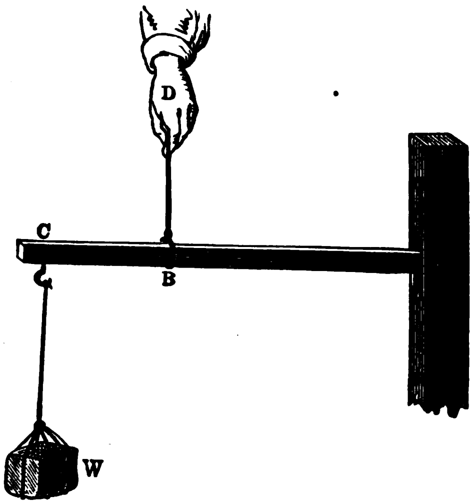

FIG. 19.—LEVER OF THE THIRD CLASS.

105. Law of the Lever.—The italics in the last article give one expression of the law of the lever. That law may be expressed in many ways. In proportion it would be

$$p : w :: \text{weight-arm} : \text{power-arm}.$$

As an equation this becomes

$$p \times \text{power-arm} = w \times \text{weight-arm},$$

or, the moment of the power = the moment of the weight.

Note.—In the above, p represents the power, and w the weight, and these letters will be so used hereafter in all problems relating to machines.

106. In levers of the second class the power-arm is the whole lever, and therefore always greater than the weight-

arm. In levers of the third class the weight-arm is the whole lever, and always greater than the power-arm. In levers of the first class, each arm is a part, only, of the lever, and the position of the fulcrum determines which is longer. Therefore power is always gained by using a second-class lever, always lost by using a third-class lever, and gained or lost by using a first-class lever, depending on whether power or weight has the longer part of the lever.

107. To gain intensity of force by the use of a lever we want all the *leverage* possible, and this is accomplished by getting the weight as near as possible to the fulcrum. Notice that the spaces traversed by power and weight are inversely as the power is to the weight. (Art. 102.) Any force or weight multiplied by the distance it moves is called the "work done" by that force or weight. Hence the law applied to all machines:

The work done by the power is equal to the work done by the weight or load.

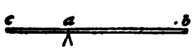

Fig. 20.

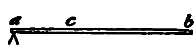

Fig. 21.

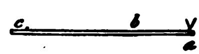

Fig. 22.

Exercises.—(In these problems, the power is always applied at b, the weight rests at c, and a is the fulcrum.)

1. In Fig. 20, $ab = 10$ inches, $ac = 2$ inches, $p = 20$ pounds: find w.
2. In Fig. 20, $bc = 22$ inches, $p = 40$, $w = 400$: find ac.
3. In Fig. 20, $ab = 12$ inches, $ac = 3$ inches, $w = 40$ pounds: find p.
4. In Fig. 20, $p = 16$, $w = 240$: find the *leverage*.
5. In Fig. 21, $ab = 20$, $ac = 4$, $w = 75$ pounds: required p.
6. In Fig 21, $ab = 24$ inches, $p = 100$ pounds, $w = 300$ pounds: required bc.
7. In Fig. 22, $ab = 1$ inch, $ac = 12$ inches, $w = 20$ pounds: required p.
8. In Fig. 22, $ab = 2$ inches, $ac = 8$ inches, b moves at the rate of 3 feet per second, at what rate does c move? $w = 3$ pounds: required p.

Experiment 19.—Take a solid foot-rule, or better, a metre-stick, marked to centimetres. Procure two empty tomato-cans with wire handles, and a few pounds of nails. Place the metre on a proper fulcrum, and, with a can suspended from each end, balance it quite

accurately with the nails. Then count any number of nails into one can, and verify the law of the lever by counting the number required in the other can to balance it. Use a spring-balance for power, with a lever of the third class.

108. **The Balance.**—The balance is a lever of the first kind. Its accuracy will depend on the exact equality of the

FIG. 23.—THE BALANCE.

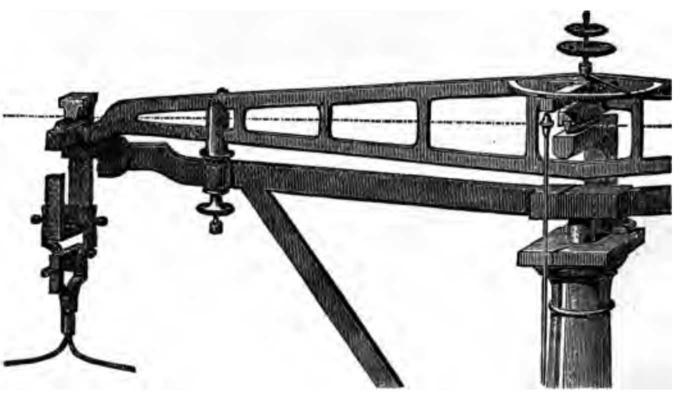

FIG. 24.—ARM OF A DELICATE BALANCE.

two arms, and may be tested by first weighing a substanc then reversing weights and substance. If they sti ance, it is correct.

THE WHEEL AND AXLE.

109. **Definition.**—The wheel and axle as a mechanical power consists of a wheel attached to an axle so that they turn together. The power is applied to the circumference of the wheel, and the weight is hoisted by a cord wound on the axle. A crank may take the place of the wheel.

110. **Law of Wheel and Axle.**—The principle of the wheel and axle is the same as that of the lever.

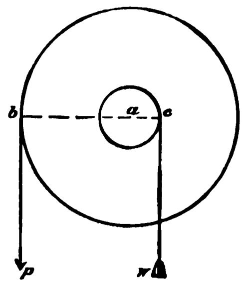

FIG. 25.—WHEEL AND AXLE.

The radius of the wheel *ab* is the lever-arm of the power, and the radius of the axle *ac* is the lever-arm of the weight. There is equilibrium when

$$p \times ab = w \times ac.$$

Having given any three of these, the fourth can be found as in the case of the lever.

The other statements of the law of the lever apply also to the wheel and axle.


FIG. 26.—WINDLASS.

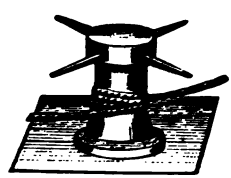
FIG. 27.—CAPSTAN.

(Fig. 26) and capstan (Fig. 27) are ex-
le.

111. Cog-Wheels.—If the wheel or the axle has teeth which work into similar teeth in other wheels, we will have a train of cog-wheels. The law of equilibrium of such a train is: the weight multiplied by the product of all the radii of the axles is equal to the power multiplied by the product of all the radii of the wheels.

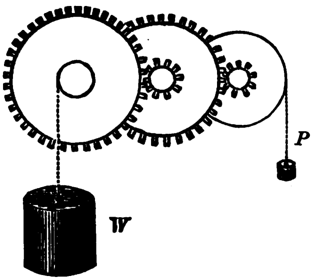

FIG. 28.—TRAIN OF WHEELS.

Since the teeth of a small wheel are the same distance from one another as the teeth of a larger wheel in which it works, when it makes a complete revolution the larger one has only turned part way round. If one has half as many teeth as the other, it will make two revolutions to one of the other. It will, therefore, travel twice as fast. But the number of teeth is proportional to the circumferences, and hence to the radii, of the wheels. Hence we have the principle that the velocity of connected wheels is inversely proportional to their radii.

112. Train of Wheels.—An axle with cogs is called a *pinion*. If a power turns a wheel the pinion of which works in another wheel, the pinion of this in another wheel, and so on, we have great increase of power, but we lose velocity. If we apply our power to the other end of the train, the last wheel, we gain great velocity when we reach the first pinion, but we lose power in the same proportion. The first method is used when we want a small power to move a heavy weight, and the latter when we want to gain a great velocity.

Wheels may also be connected by means of belts. The circumstances of motion are the same as in a train of cog-wheels. In this case the friction between the belt and the surface of the wheel takes the place of the cogs, and the advantage is that power can be communicated through a long distance.

Exercises.—In the following examples let R stand for the radius of the wheel and r for the radius of the axle.

1. Given $R=20$, $r=5$, and $P=200$, to find W.
2. Given $R=20$, $P=100$, and $W=1000$, to find r.
3. Given $R=20$, $r=\frac{1}{2}$, and $W=500$, to find P.
4. Given $r=\frac{1}{2}$, $W=1000$, and $P=40$, to find R.
5. In lifting an anchor which weighs 1000 pounds, four men work a *capstan* having a radius of 2 feet, by bars the outer ends of which are

6 feet from the centre of the barrel. How much force does each exert? *Ans.* 83.3 + pounds.

6. A power of 5 pounds acts on a wheel with a radius of 1 foot. The pinion (2 inches radius) acts in a wheel of 1 foot radius. This is repeated 3 times. What weight may be lifted? *Ans.* 1080 pounds.

7. Given $R = 50$ centimetres, $r = 10$ centimetres. The power, 10 kilograms, required W. The power falls 20 metres. How far will it hoist W?

THE PULLEY.

113. **Fixed Pulley.**—The pulley consists of a wheel working in a block. In its simplest form it is used to change the direction of a force. In this case there is no power gained; a little is lost by friction and by the stiffness of the rope; but, except these, it is carried over without loss or gain. In Fig. 29 the downward force becomes an upward one, and can be applied to lifting weights. Such a pulley is called a *fixed pulley.*

114. **Movable Pulley.**—The case is different when we have a pulley such as is shown in Fig. 30. Here the

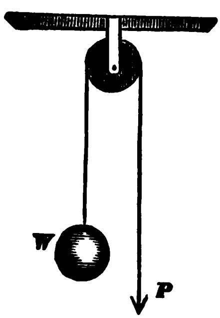

FIG. 29.—FIXED PULLEY.

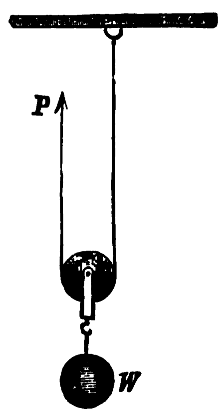

FIG. 30.—MOVABLE PULLEY.

weight is supported by both branches of the cord above the pulley, hence the tension on each need be but half the weight; that is, for equilibrium, W must be twice P.

A pulley of this kind will, therefore, enable a power of one pound to lift a weight of two pounds. Such a pulley is called a *movable pulley*.

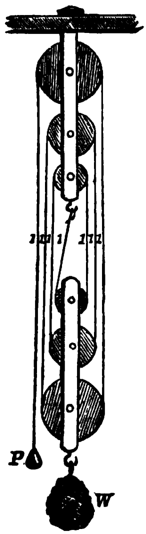

FIG. 31.—COMBINATION OF PULLEYS.

115. **Work done.**—Since, when *W* is lifted any distance, the pulley is elevated the same amount, the ropes at both *a* and *b* will be shortened, and *P* will have to rise through twice this distance. Hence, as in the lever, in order to gain the advantage of the movable pulley, we lose space and time. The work done by the power is equal to the work done by the weight. (Art. 107.) While in motion, the momentum of the power is equal to the momentum of the weight.

116. **Combination of Pulleys.** — Fig. 31 represents the theory of movable pulleys. To estimate the power gained let us suppose a force of one pound applied at *P*. Disregarding friction, this force of one pound is felt throughout the whole length of the rope, and, as the rope pases six times to the movable block, it (the block) will be supported by a force of six pounds.

117. **Law of the Pulley.**—*In a combination of pulleys with one rope, a power will balance a weight as many times greater than itself as the number of times the rope passes to the movable block.*

118. **The Differential Pulley-Block.**—Fig. 32 represents the differential pulley, which may be made to gain power to any extent, and is a complete example of the principle of mechanics stated in Art. 102.

The fixed pulley, or "differential pulley-block," consists of two wheels, or "sheaves," cast solidly together. The circumference of each of these sheaves is pocketed to carry the links of the chain and prevent slipping. The sheave at the back, or right-hand side of the block, contains one *more* pocket, at least, than the front sheave. To hoist the

load, the operator pulls the chain at *P*. When a given number of links, say 40, have passed through his hand, the wheel *A* has made one revolution. This takes up 40 links at *B*, and lets out 38 links at *C*, which shortens the double chain *BC* 2 links and raises *W* *one* link. (Each pocket counts *two* links.) As the operator pulls *P* forty times as far as *W* rises, 1 pound will balance 40 pounds. This pulley will sustain its load at any height without running down, by the friction of the chain and bearings. This is a great advantage. To lower *W*, the operator pulls the chain at *L*.

FIG. 32.—DIFFERENTIAL PULLEY.

The wheel *A* may be made of any size, thus diminishing the ratio of the two sheaves and increasing the power accordingly. Mechanical devices may be used to turn *A*, thus further increasing the lifting power of the pulley.

Exercises.—1. In Fig. 33, how much weight will a power of 20 pounds lift?

2. If the power moves through 30 feet, how far will the weight move?

3. How much power will be required to lift a weight of 1 kilogram through 1 metre, and through what distance will it move?

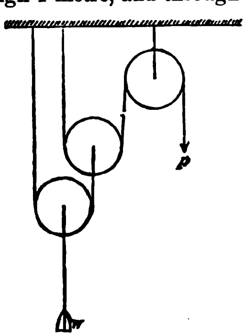

FIG. 33.—PULLEYS.

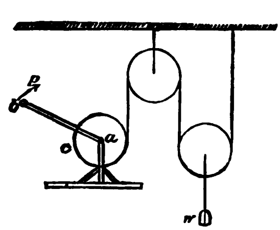

FIG. 34.—PULLEY AND WINDLASS.

4. In a system of pulleys with one rope a power of 2 pounds balances a weight of 24 pounds: how many movable pulleys are employed?

5. In the combination of pulley and windlass of Fig. 34, *ab* is 2 feet, *ac* 6 inches. A power of 30 pounds is applied at *b*: how much weight can be lifted?

6. How many turns will be required to lift the weight through 3 feet?

7. In a differential pulley-block there are 31 and 30 pockets respectively on the two sheaves. $P = 10$ pounds: required W.

8. In the differential pulley shown in Fig. 32 there are 20 and 19 pockets in the upper wheel. $W = 1000$ pounds, and the friction adds 2000 pounds: required P.

THE INCLINED PLANE.

119. **Definition.**—The inclined plane is any plane surface inclined to the horizon. A board for rolling barrels into a wagon, a railway track not level, a coasting hill, are inclined planes.

120. We best illustrate the use of the inclined plane by the board, or "skids," for loading a wagon with barrels. The skids are used to avoid the necessity of lifting the barrel perpendicularly. The work done is the weight of the barrel multiplied by the height of the wagon. A boy who could not at all lift the barrel, could roll it up the skids. In the railway, or in the common road, we may not wish particularly to place the load on the hill-tops, but if a hill-top is in the line of the road, and cannot be cut away, we must surmount it to gain the farther side, and the load must be raised the height of the hill. The slope of a railway is called its *grade*, and the steepness of the grade is generally denoted by giving the number of perpendicular feet per mile. In a road with a grade of 66 feet per mile, the rise would be 66 feet in 5280, or 1 foot in 80. For a small plane we would call this a grade of 1 in 80. On such a plane a pressure of 1 pound would hold a weight of 80 pounds; that is, would prevent it from rolling down, the other 79 pounds being supported by the plane. This holds good in any case, and gives us the

121. **Law of the Inclined Plane.**—*A given power, acting parallel with the plane, will balance a load as many times greater than itself as the length is times greater than the height of the plane.*

Here the work done by the power is the power multiplied by *the whole distance it moves*, and the work done by

the weight is the weight multiplied by the distance it *rises vertically*.

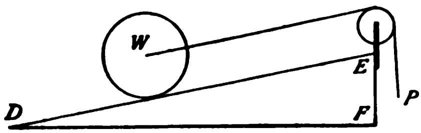

FIG. 35.—INCLINED PLANE.

Exercises.—1. In Fig. 35, $DF=20$, $EF=4$, $W=500$ pounds: find P.

2. In the same figure with the same dimensions, $P=250$ pounds: find W.

3. A boy, who can push 100 pounds, wishes to roll a barrel of oil, weighing 500 pounds, into a wagon 4 feet high: how *long* must his skids be?

4. A locomotive which can exert a continuous pull of 15,000 pounds on a train is required to draw a train weighing 990,000 pounds: what is the steepest grade it can overcome?

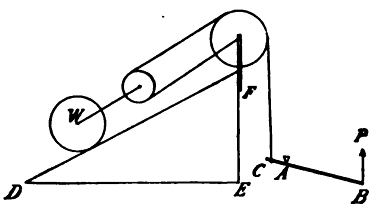

FIG. 36.—COMBINATION OF POWERS.

5. In the combination of lever, inclined plane, and pulley of Fig. 36, $AB=10$ feet, $AC=2$ feet, $DF=20$ feet, $EF=8$ feet, $P=100$ pounds: how large a weight can be lifted?

6. How much power will be needed to lift a ton?

7. How far will P have to move to drag W through 1 foot?

THE WEDGE AND SCREW.

122. The Wedge.—If the inclined plane is pushed under the body, it becomes a wedge, and the same rules for equilibrium hold good. The height of the plane is now the back of the wedge, and the weight is as many times greater than the power as the length exceeds the back of the wedge.

Wedges are used for splitting timber, for raising heavy

weights, for cutting and piercing. Knives, scissors, awls, chisels, pins, needles, are wedges.

123. **The Screw.**—A screw is an inclined plane wound around a cylinder.

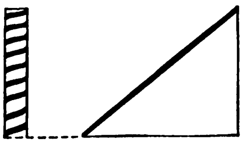

FIG. 37.—SCREW AND INCLINED PLANE.

Experiment 20. — Take a triangle of paper, as in Fig. 37, and wind it around a cylinder of wood; it will illustrate how an inclined plane can be made into a screw.[1]

124. **Law of the Screw.**—One complete turn of the screw will lift the weight through the distance which separates the threads. The law of the screw is, therefore, that the pressure exerted is as many times greater than the power as the circumference described by the power is greater than the distance between the threads.

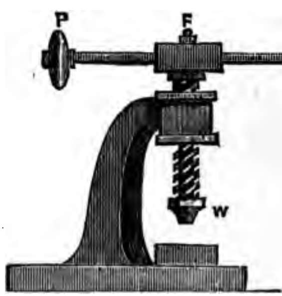

FIG. 38.—THE SCREW.

Exercise. — A power of 30 pounds applied at the end of a lever 2 feet long acts on a screw, the distance between the threads of which is $\frac{1}{20}$ of an inch: how much weight can be lifted?

In the common screw, propelled by a screw-driver, the weight is the resistance of the material penetrated, and the circumference described by the power is the circle through which the largest part of the handle travels.[2]

125. **Friction.**—All the laws of machines are modified by *friction*. Friction is roughness at the point of contact of two surfaces, which prevents them from sliding freely on each other. In levers there is friction at the fulcrum, in the wheel and axle and pulley at the bearings, on the

[1] Such a curve is a helix, and not a spiral, as often stated. A spiral is a curve in one plane.

[2] The distance between the threads of a fine screw is best obtained *by measuring* an inch along it and counting the number of threads.

inclined plane, wedge, and screw, at their surfaces. In all these cases this represents so much resistance, to overcome which additional power is required. It is important to ascertain the amount of friction between surfaces of different kinds, so that its effect may be accurately taken into account in our theories of machines. The following will afford a means of testing its amount.

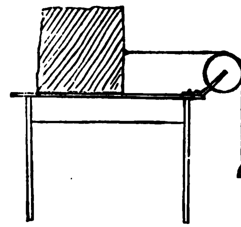

FIG. 39.—DETERMINING FRICTION.

Experiment 21.—Fasten a pulley to the table, as in Fig. 39. Place a block on the table and attach the pulley-cord to it. On the other end of the cord apply weights till the block begins to move. The amount of these weights will measure the friction between the block and the table.

Experiment 22.—Place a brick on end, then on face on the table; the friction will be the same in both cases.

Place a second brick on top of the first; the friction will be doubled.

126. **Laws of Friction.**—By some such arrangement as this it has been found,—

1. That friction is less between metals of different kinds than between metals of the same kind. Hence the advantage of brass bearings for iron axles.

2. That it is proportional to the weight (or pressure), and does not depend on extent of surface in contact.

3. That it is greater at the start than after motion has commenced. A part of the weight may be removed from the cord, and it will continue to descend.

The object of lubricants is to diminish friction.

127. **Friction Essential.**—Friction should not be looked upon as a resistance merely: it is indispensable to our welfare. It is the friction between our feet and the ground which saves us from falling at every step. It is the friction between the particles of dirt and the rocks which prevents all the hills from crumbling down and everything being reduced to a dead level. It is the friction of nails and screws which gives them their utility and prevents all our struc-

tures from falling to ruins. It enables the engine to draw us on the track; it gives to belted wheels their value; it enables us to make long ropes of short strands, and keeps knots tied; it prevents the rivers from flowing with the velocity of falling bodies.—(Art. 156.)

128. **Machines do not create Energy.**—We have seen both in the lever and in the pulley that the work done by the power is equal to the work done by or upon the weight or resistance. This is a general law of machines. Whenever we gain power we lose speed, and when we gain speed we lose power. A machine cannot create any energy. It transmits that which is applied to it by an external power. The power does work upon it, and it does work upon the resistance. This work may be of a different kind, but is the same in amount.

129. **Uses of Machines.**—The question then comes up, What do we gain by machines? Sometimes we gain only a change of direction, as in the fixed pulley; sometimes it is an advantage to gain power at the expense of velocity, as in a lever or pulley used to raise a heavy weight; and sometimes it is an advantage to gain velocity at the expense of power, as in the case of a clock, where the slow falling of the weight, or uncoiling of the spring, may cause more rapid motion of the hands. Sometimes it is a gain to change the character of the power, as in the steam-engine, where heat produces mechanical motion, or in electric-lighting machines, where heat and motion produce electricity and light. Machines are also a great gain in enabling us to use the power of the wind, of steam, of falling water, and of animals.

130. **Perpetual Motion.**—These examples will show the character of the gains of machinery. In no case is the energy increased by the machine itself. We see, then, the folly of all *perpetual-motion* machines,—machines which will keep themselves running without the addition of any external energy. Any such machine would have to create

energy. Let us suppose that water falling on a wheel would cause such motion of the wheel as would, applied to a pump, force the water up to the level from which it fell. This would be a perpetual-motion machine, for it would keep itself going forever without any new supplies of force. But it requires just as much energy to lift the water up to its level as is given out by the fall. But part of the energy of the fall is required to overcome the friction of the machinery and the resistance of the air, hence there cannot be enough left to raise the water to its old level. If machines could be constructed so as to run without any resistance, perpetual motion would be possible, and under no other circumstances.

Such a machine would be useless for any practical purposes, for if any machinery were connected with it, it would soon bring it to rest, and a new supply of power would be needed.

General Exercises.[1]—1. The minute-hand of a watch is twice as long as the second-hand: show that the end of the second-hand moves thirty times as fast as the end of the minute-hand.

2. Find the space described in the fifth second by a falling body.

3. If a body falls for a quarter of a minute, show that at the end of that time it would be moving at the rate of 483 feet per second, and ascertain what this velocity will be, expressed in miles per hour.

4. A stone dropped into a well is heard to strike the water in two seconds and a half: find the depth of the well. *Ans.* 100 feet.

5. An express train, 66 yards long, moving at the rate of 40 miles an hour, meets a slow train, 110 yards long, moving at the rate of 20 miles an hour: find how long a man in the express train takes to pass the slow train, and how long the express train takes in completely passing the slow train. *Ans.* $\frac{1}{18}$ minute. $\frac{1}{10}$ minute.

6. A river, one mile broad, is running downward at the rate of 4 miles an hour; a steamer can go up the river at the rate of 6 miles per hour: find at what rate it can go down the river. *Ans.* 14.

7. A moving body is observed to increase its velocity by a velocity of 8 feet per second in every second: find how far the body would move from rest in 5 seconds. *Ans.* 100 feet.

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[1] In these and other exercises at the ends of the chapters a great variety is given. The teacher should make a selection adapted to the class. Many classes had better omit all of them, while some would be benefited by working them all.

8. Show that a cylinder, if placed on its flat end, will be in stable equilibrium, but, if placed on its curved surface, in neutral equilibrium.

9. A triangular board is hung by a string attached to one corner: find what point in the opposite side will be in a line with the string.

10. Find where the fulcrum must be plaeed that 2 pounds and 8 pounds may balance at the extremities of a lever 5 feet long.

11. The arms of a lever are respectively 15 and 16 inches: find what weight at the end of the short arm will balance 30 pounds at the end of the long arm, and what weight at the end of the long arm will balance 30 pounds at the end of the short arm.

12. A straight lever, 6 feet long, and heavier towards one end than the other, is found to balance on a fulcrum 2 feet from the heavier end, but when placed on a fulcrum at the middle it requires a weight of 3 pounds hung at the lighter end to keep it horizontal: find the weight of the lever. *Ans.* 9 lbs.

13. Two men, A and B, carry a weight of 200 pounds on a pole between them; the men are 5 feet apart, and the weight is at a distance of 2 feet from A: find the weight which each man has to bear.

14. Suppose that a body which really weighs 1 pound appears in a balance to weigh 1 pound 1 ounce: find the proportion of the length of the arms.

15. A substance is weighed from both arms of a false balance, and its apparent weights are 9 and 4 pounds: find the true weight.

16. The radius of the axle of a capstan is 1 foot: if four men push each with a force of 100 pounds on spokes 5 feet long, show that on the whole a tension of 2000 pounds can be produced on the rope which passes around the axle.

17. A wheel and axle is used to raise a bucket from a well; the circumference of the wheel is 60 inches, and while the wheel makes three revolutions the bucket, which weighs 30 pounds, rises 1 foot: find the smallest force which can turn the wheel. *Ans.* 2 lbs.

18. Suppose the power to act parallel to the plane, and that the height of the plane is to its base as 5 is to 12: if the weight is 65 pounds, find the power. *Ans.* 25 lbs.

19. Find the relation between the power and the weight in a screw which has 10 threads to an inch, and is moved by a power acting at right angles to an arm at the distance of 1 foot from the centre.

20. A pendulum vibrates 65 times in a minute: how much must it be lengthened to vibrate once in a second?

Suggestion.—Time of one vibration $=\frac{12}{13}$ seconds. *Ans.* $\frac{25}{144}$ of its length.

21. In what time would a seconds pendulum vibrate at a height of 4000 miles above the earth's surface? at a depth of 2000 miles under ground?

22. How long is a pendulum which vibrates 40 times a minute, a seconds pendulum being 39.1 inches long?

23. A seconds pendulum carried up a mountain vibrates 58 times a minute: what is the force of gravity? *Ans.* $\frac{841}{900}$ of gravity at the surface. This would be expressed by saying it would cause an acceleration in a falling body of 30.1 feet per second. Work out this result.

SUMMARY OF CHAPTER II.

Change from a state of rest to a state of motion, or *vice versa*, is always produced by the application of some *force*.

Forces are either impulsive or continuous.

An impulsive force tends to produce uniform motion, and a continuous force tends to produce accelerated motion.

The fundamental relations of motion and force are expressed in the three laws of motion first stated by Sir Isaac Newton.

The momentum of a moving body is its ability to impart motion to another body.

Forces may be measured either by the pressure which they cause or by the acceleration they can produce in bodies free to move.

The C. G. S. unit of accelerating force is the dyne. This is the force which will accelerate a mass of one gram at the rate of one centimetre per second.

The dyne in the middle United States is about $\frac{1}{980}$ of a gram.

Two forces acting on a body in any direction, not in the same straight line, will move it to the opposite corner of a parallelogram, of which the two sides represent the magnitude and direction of the two forces.

When a body in motion is acted on by a continuous force towards any point out of the line of motion, its path is a *curve*.

Work consists in *causing motion against resistance*.

The practical units of work are the foot-pound and the kilogram-metre. The invariable unit is the erg.

Power is estimated in units of *work* and *time*.

The practical unit of power is the horse-power,—*i.e.*, the ability to lift thirty-three thousand pounds one foot in one minute.

Energy is ability to do work.

Potential energy is the energy possessed by a body or a substance on account of its position, or state of compression or strain.

Kinetic energy is the energy which a body possesses on account of its *motion*. Its amount is determined by the *weight* as well as the *velocity* of the body.

A body starting to move is converting potential energy into kinetic energy; a body stopping in a position of increased advantage is converting kinetic energy into potential.

Energy is indestructible. It may undergo countless transformations, but the total amount in the universe is always the same.

The centre of gravity of a body is the point on which the body will balance.

A body is stable when, the centre of gravity being moved, it tends to return to its original position.

The earth's attraction (gravity) causes a velocity of about 32.2 feet, or 9.8 metres, per second in a body free to fall. This acceleration is practically the same for all bodies, light and heavy, and whether they have a motion horizontally or not.

Gravity *takes from* the velocity of a body moving upward 32.2 feet each second.

The resistance of the air seriously modifies the results of calculation for very rapidly-moving bodies or bodies of light material.

A swinging pendulum is a complete example of the conversion of potential into kinetic energy, and *vice versa.*

All machines are combinations of the six mechanical powers, the lever, wheel and axle, pulley, inclined plane, wedge, and screw, some of them frequently much modified.

In all machines velocity of motion is gained only at the expense of intensity of pressure, and *vice versa.*

The principle of all machines is that the *power* multipled by the distance it *moves* is equal to the *weight* multiplied by the distance it *rises.*

All the laws of machines are much modified in practice by rigidity of ropes and other material, and by various other resistances, the principal one of which is *friction.*

No machine, however nearly perfect, can create or originate any energy, power, force, or work: it simply affords a convenient method of applying the kinetic energy of moving air and falling water, the radiant energy of light and heat, the subtle energy of electricity, and the vital muscular energy of ourselves and our domestic animals, to such purposes as we choose.

CHAPTER III.

LIQUIDS.

SECTION I.—HYDROSTATICS.

131. **Definitions.**—In Art. 32 we were taught that liquids are substances in which there is perfect freedom of the molecules among themselves, and that they change their form with the slightest force. No liquid fulfils these conditions perfectly, but many do this near enough for all practical purposes. Water is commonly used as the typical liquid, and will be so used here.

Liquids will be treated under two heads,—liquids at rest and liquids in motion. *Hydrostatics is the science which treats of liquids at rest.*

132. **Liquids almost Incompressible.**—Liquids can scarcely be compressed even if subjected to the greatest pressure. Indeed, it was formerly thought that they could not be compressed at all. Many years ago some philosophers in Florence filled a hollow silver ball with water, and, after closing the opening, squeezed the sides together by great pressure. This pressed the ball out of its spherical shape, and, as this would make the cavity smaller,[1] they hoped to

[1] It is proved in higher mathematics that a hollow sphere has a greater capacity than a vessel of any other shape which is enclosed by the *same surface.* Hence, when the shape of the silver vessel was changed, its shell would not hold so much water; but, as indicated above, instead of shrinking to fit its smaller quarters, the water oozed through the sides.

Tyndall calls attention to the fact that Bacon performed this experiment fifty years before it was performed in Florence; but this fact is generally unknown, and Bacon seldom gets credit for it.

compress the water. But, instead of shrinking in bulk, the water came through the thick silver sides, *and spread over the outside like dew.*

But by using better apparatus modern experimenters have been able to compress water and other liquids slightly. To compress a quantity of water whose upper surface is a foot square into a bulk only $\frac{1}{100}$ less would require a pile of iron weights, each 1 foot square, *more than $\frac{1}{8}$ of a mile high.* For all practical purposes, therefore, water is incompressible. This property of liquids will be illustrated presently in water machinery, and is of great use to us there.

133. **Liquids perfectly Elastic.**—If liquids are compressed, and even if kept compressed for a great length of time, they always expand to their original bulk when the pressure is removed. Hence we infer that they are perfectly elastic.

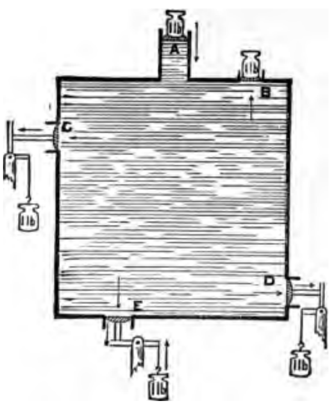

FIG. 40.—THE PRESSURE OF LIQUIDS THE SAME IN EVERY DIRECTION.

Experiment 23.—Throw a flat stone very slantingly on the surface of a pond of still water, and notice how it rebounds or "skips" again and again. What causes it? Does a stone skip so well on smooth ice? Why not?

134. **Liquids transmit Pressure equally in all Directions.**—The most remarkable and important fact about liquids is that whenever any pressure is put upon one, *the liquid presses out with the same force in every direction.*

In Fig. 40, the piston A presses down upon one square inch of water with a force of 1 pound. This force is transmitted to every part of the surface, and the liquid therefore presses with the force of 1 pound upon each square inch of the surface of the vessel, as is shown by its sustaining the weights at B, C, D, and E.

To which class does the lever at C belong? at D? at E? Has

the weight of the water been taken into account here? Would it make any difference?

135. **The transmitted Pressure proportional to the Surface.**—In Fig. 41, if the small tube is 1 inch square and the large one 4, then the area of the water pressing on the large piston is 16 times[1] as great as upon the small one, and with an upward pressure of 1 pound upon each square inch of B, the whole upward pressure then is 16 pounds. This is called the hydrostatic paradox, because it seems paradoxical (or beyond belief) that 1 pound should balance 16 pounds.

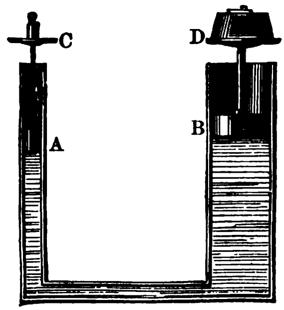

FIG. 41.—THE HYDROSTATIC PARADOX.

136. **The Hydrostatic Press.**—If more than a pound be placed upon C (Fig. 41), the piston A will be forced down and D will be raised. In this way a small weight can be made to raise a very large one. This is the principle of the hydrostatic press, which is shown in Fig. 42. In order that all of the parts, and the manner of working, may be seen, the figure represents the press cut open through the middle, or *in section*, as this is called. The raising of the piston *p* sucks up water from *m*. When the handle HE is pushed down again, a valve keeps the water from going back into *m*, and it is forced through the narrow tube into M, and the large piston P is raised and pressed against the cotton-bale C with great force. If *p* is 1 inch in diameter, and P 10 inches, for every pound down upon *p* there is a pressure of 100 pounds upon the cotton-bale. This force is usually further increased by using a lever, GE (which class?), to increase the pressure upon *p*.

[1] The student will not forget that the *areas* of similar surfaces vary according to the *squares of* their like dimensions.

137. The Hydrostatic Press creates no New Force.—The hydrostatic press may seem to contradict Art. 130, where it is said that power is never created by machinery. But

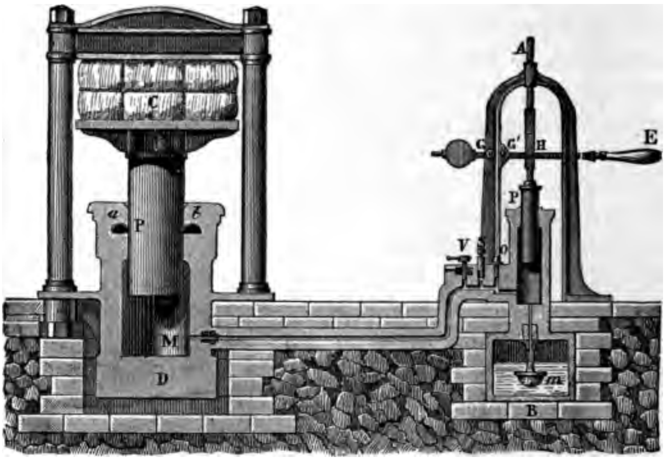

FIG. 42.—THE HYDROSTATIC PRESS.

the surface of the water which presses up against P is 100 times as great as that pressed upon by *p*, and therefore when the small piston has been forced down 1 foot P has been raised only $\frac{1}{100}$ of a foot. So that our force of 1 pound moving through 1 foot has been changed to a force 100 times as great, but moving through only $\frac{1}{100}$ of a foot, and therefore exactly equivalent to the first force.

The loss of power by friction has not been taken into account here, and less power is lost by it in this machine than in almost any other.[1] On this account, and because

[1] About 10 per cent. of the power is usually lost by friction. The principle of the hydrostatic press has been known for more than two hundred years, but no way of making the joints tight enough to resist the enormous pressure of the water was found until Bramah, an English inventor, about the beginning of the present century, invented a *curved leather* collar for this purpose, shown in Fig. 42, at *a* and *b*.

by enlarging P almost any power can be accumulated there, this machine is in common use where great force is needed.

138. **Pressure on the Bottom of a Vessel.**—In a vessel whose bottom is level and sides perpendicular, the pressure of the water upon the bottom is evidently equal to its weight, as in Fig. 43, A. If, now, a vessel with a narrow stem, but widening into a broad base, as in Fig. 43, B, be filled with water, the water at *a*, being pressed upon by the weight of the column of water above it, transmits this pressure equally in *every* direction to the water surrounding it. This does the same in turn, so that the pressure on every part of the bottom of the vessel is the same as on the part under the column. Then, in Fig. 43 C, the pressure at E is equal to that at D, and therefore the pressure at F (or at H), is the same as it would be at *f* if the first joint of the pipe were extended straight down to *f*. And also the pressure at M or O is the same as it would be at

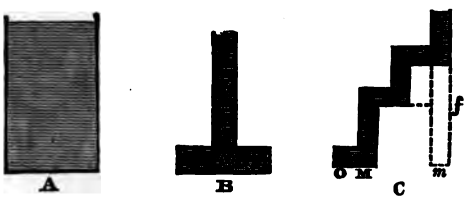

FIG. 43.—PRESSURE VARIES WITH THE DEPTH.

m. If the tubes were curved, or had any other shape, the pressure on the bottom would be the same. Hence the following important principle: *In a vessel of any shape whatever, the pressure of a liquid upon the bottom is the same as if the sides rose perpendicularly around the bottom, and it were filled with the liquid to the same height.*[1]

The space underneath this collar is connected with M, so that the water presses the collar tighter above the piston as the pressure in M grows greater, and prevents the water from leaking there. From this discovery the hydrostatic press is sometimes called Bramah's press.

[1] The bottom of the vessel is understood to be horizontal,—that is,

A cubic foot of water weighs 1000 ounces, or $62\frac{1}{2}$ pounds.[1] Therefore, to find the pressure of water on the bottom of a vessel, find the number of cubic feet in a column of water whose base is the bottom[2] of the vessel and whose height is the *perpendicular* height of the surface of the water above the base, and multiply $62\frac{1}{2}$ pounds by this number.

139. Pascal's Experiment with the Vases.—The apparatus

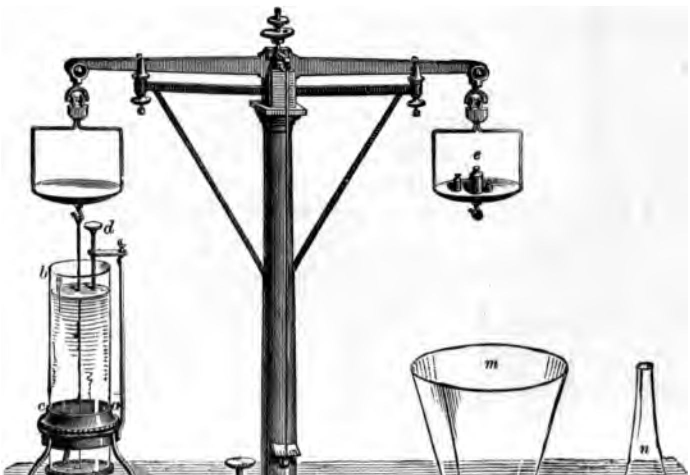

FIG. 44.—PASCAL'S VASES.

shown in Fig. 44 was devised by Pascal[3] to prove these truths ex-

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level. For the pressure upon the bottom when it is not horizontal, see Art. 140.

[1] More exactly, a cubic foot of *pure*, *fresh* water at 32° F. (what does that mean?) weighs $62\frac{417}{1000}$ pounds, and slightly less at higher temperatures. A cubic foot of sea-water weighs about $64\frac{1}{3}$ pounds.

[2] Should the outside or the inside area of the bottom be taken?

[3] Pascal (Pas'kal) was born in France in 1623, and died there in

perimentally. The bottom of the glass tube *ca* is loose, and hangs by a string from one arm of a balance. Small weights are put on the other arm until they balance the bottom and the string. The glass tube *bc*, whose sides are perpendicular, is screwed on at *c*, an additional weight of 1 pound is put into the scale-pan *e*, and water is poured into *bc*. The pound-weight holds the bottom close against the end of the tube until a *pound* of water has been poured in. Then the water pushes the bottom down, and runs out as fast as more is poured in, the marker *d* having been set so as to show the height of the water when it began to run out.

If, now, *bc* be unscrewed and *m* be screwed on in its place, it will be found that water must be poured in to exactly the same height as at first before it will loosen the bottom and run out, although, because of the widening out of *m*, there may be 2 pounds of water in it then, thus proving that *the pressure on the bottom depends only upon the area of the bottom and the perpendicular height of the water.* If *n* be used, perhaps half a pound of water will fill it up to the marker *d* and start the flow of water.

140. **Pressure on the Sides of a Vessel.**—Since the pressure is transmitted equally in all directions, at the edge of the bottom of a vessel the pressure of the liquid on the side is the same as on the bottom. Half-way up to the surface it is the same as the downward pressure at that depth, or half as great as at the bottom. At the surface there is no pressure on the side. Therefore the *average* pressure per square inch on the side is half as great as on the bottom. If, then, a cubical vessel be full of water, the pressure upon each of the four sides is one-half that upon the base.

In the above case the sides of the vessel are supposed to be rectangles, perpendicular to a horizontal base. In general, the average pressure upon the perpendicular sides of *any* shape is the pressure upon the centre of gravity of the part of that side under water.

If the side of a vessel is not perpendicular, the pressure upon the part of the side under water is the same as if that part were laid level and covered with water to the *average* depth of the water upon the inclined side, or to the depth of the centre of gravity of the side.

1662. He was a very brilliant scientist, who did much for Natural Philosophy, especially in the subject we are now considering. He wrote a book on Conic Sections when in his sixteenth year.

A vessel's *base*, which is not horizontal, may be considered as an inclined side, and the pressure upon it found in the same way. This is a different thing from the *downward* pressure in such a vessel. That is the same as the *weight* of the water, and would be found by taking a *horizontal section through the water* and its average depth.

141. **Pressure on the Top of a Vessel.**—There may also be an upward pressure upon the top of a vessel. Thus, in a vessel shaped as in Fig. 45, the pressure upward at H or F is just the same as the pressure downward at B.

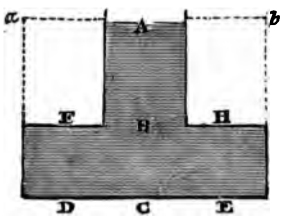

FIG. 45.—UPWARD PRESSURE OF LIQUIDS.

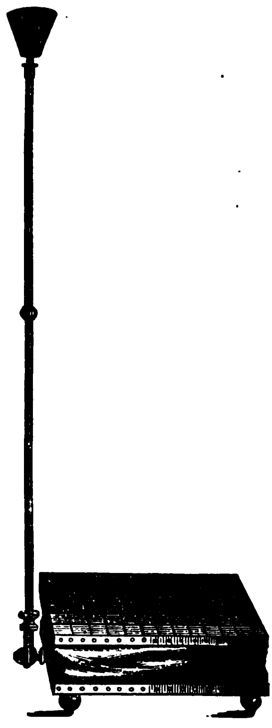

FIG. 46.—THE HYDROSTATIC BELLOWS.

Students sometimes cannot see how the pressure upon the bottom DCE can be as great as if the sides went up to *a* and *b*, and yet when put upon scales and weighed the whole will not weigh nearly so much as the other vessel of water would. It is because the pressure upward at F and H counterbalances a part of the pressure downward at D and E. A foot-ball might be blown so full that the air would press outward against the cover with a force of several pounds to the square inch, and yet ordinary scales would not show it to be any heavier than when empty. The pressure within is as great up as down, and so does not add to the weight.

142. **The Hydrostatic Bellows.**—Fig. 46 shows a common piece of apparatus which well illustrates these principles.

Suppose the top of the bellows to have an area of 144 square inches, and the tube an area, in cross-section, of one square inch. One pound of water in the tube would press with a force of one pound on every square inch of the bellows, and would support a weight of 144 pounds on its top. A pound of water in a tube an inch square would fill the tube to the height of about 27½ inches. Now if this tube be unscrewed, and a tube one-tenth of a square inch in cross-section be screwed in, a column of water in that tube 27½ inches high, and weighing only one-tenth of a pound, will support the same weight on the bellows, 144 pounds. The tenth of a pound pressure is felt on each tenth of a square inch, and as there are 1440 tenths of an inch, it supports 1440 tenths of a pound, or 144 pounds. By making the tube 55 inches high we get a pressure of 288 pounds per square foot, and so on, increasing 144 pounds for each 27½ inches of height, no matter what the diameter of the tube.

Few persons appreciate the amount of pressure caused by a considerable depth of water. Pascal long ago showed that a strong cask could be burst by screwing into it a long tube and filling cask and tube with water. Tanks and cisterns would be much less likely to leak if made wide and shallow, than if made narrow and deep. The pressure in the water-pipes of cities and towns is often very great.

When pipes are to carry water to a great height, they should be made of small diameter if circumstances will admit of it, so that they will have but few square inches for the water to press upon.

Exercises.—1. If in the vessel shown in Fig. 41 one side of A is 2 inches and one side of B 12 inches, and if 5 pounds were put upon C, what weight upon D would it balance? *Ans.* 180 pounds.

2. In a hydrostatic press the diameter of the small piston is 1 inch and that of the large piston 12 inches: how great a weight will be raised by a downward pressure of 50 pounds upon the small piston? *Ans.* 7200 pounds.

3. If GE (Fig. 42) is 3 feet and GH 6 inches, what weight will be balanced by 50 pounds at the end of the handle? *Ans.* 43,200 pounds.

4. There are 2150.4 cubic inches in a bushel: what weight of water would fill a peck measure? *Ans.* 19⅜ pounds.

5. If the room in which you recite these lessons were filled with water, what would it weigh?

6. A *cubical* vessel is full of water: how many times its weight

is the pressure of the water upon the sides and bottom together? *Ans.* 3 times.

143. **Surface of Still Water.**—Particles of water being free to move, the effect of gravity on any particle of a surface not strictly horizontal would be to move the particle sidewise, and this motion of particles would continue until the action of gravity on every particle would be exactly perpendicular to the surface. It thus results that *a free surface of still water is always level.*

143*a*. **Liquids in Communicating Vessels.**—The same principle that keeps the surface of still water level, that is, *all parts equally distant from the earth's centre,* keeps the water in pipes or other communicating vessels at the same *height.* The water-works of a town illustrate this on a large scale. The water tends to rise in the pipes which supply the houses to the height of the surface of the water in the reservoir or standpipe. The common tea-kettle and coffee-pot are smaller illustrations of the same principle, the liquid rising as high in the spout as in the pot.

If liquids of different density which will not mix are put in communicating pipes, the heights to which they rise are inversely proportional to their specific weights. (See Art. 151.) Mercury is about 13½ times as heavy as water, and a water engineer with a glass tube 5 feet long filled with mercury and screwed into a water-pipe in his engine-room, may at any moment determine the depth of water in the reservoir 65 feet above him.

Explain this. How much would the mercury fall in the gauge if the water should fall 2 feet 3 inches in the tank?

144. **Fountains, Springs, Wells.**—It is the tendency of water to rise to the height of its reservoir that causes fountains and artesian wells. The stream never actually reaches the level of the reservoir, however, on account of friction, resistance of the air, and the interference of falling drops. In fact, for a house-supply of water, the reservoir must be above the level of the house if the water is to *flow* from the pipes in considerable quantity.

When rain falls, it sinks down into the earth until it comes to a layer of rocks or clay, and flows along this to an outlet, generally where the surface of the ground sinks down to the level of the bed of clay or rock. This is a *spring*. Where there is no spring, a pit is often dug down until it reaches one of these small underground streams, and we have a *well.*

Artesian wells are small holes only a few inches in diameter, bored into the earth with a sort of auger. They are often many hundreds of feet deep, and the water rises in them, sometimes flowing out at the surface. This is because the well has tapped an underground stream of water which has flowed down there from high ground. Fig. 47 makes this clear.

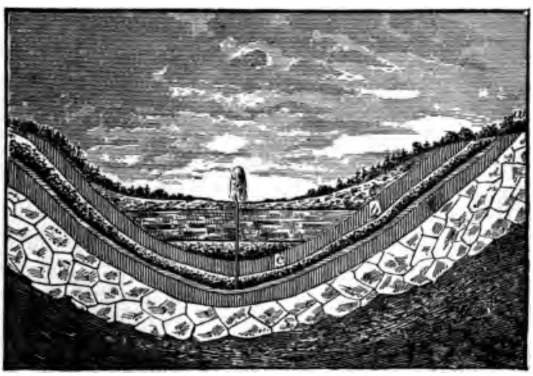

FIG. 47.—AN ARTESIAN WELL.

The water has flowed from *a* under a stratum of clay or rock, *bc*, through which the water cannot rise anywhere until the well is reached. These wells have been sunk in all parts of the world, and from some of them immense quantities of water flow.[1] Many of the oil-wells in Pennsylvania and elsewhere are artesian wells.

[1] These are called artesian because the first one was at Artois (Ar-twä′) in France.

At Passy (Päs-see′), near Paris, there is an artesian well 1923 feet deep, which discharges 5,660,000 gallons of water daily.

145. Water-Level.—The surface of a small portion of water appears to be perfectly level, and is practically so, but large surfaces of water are found to be perceptibly convex.[1] This necessarily follows from the fact that the earth is round, the water taking the shape of the earth.

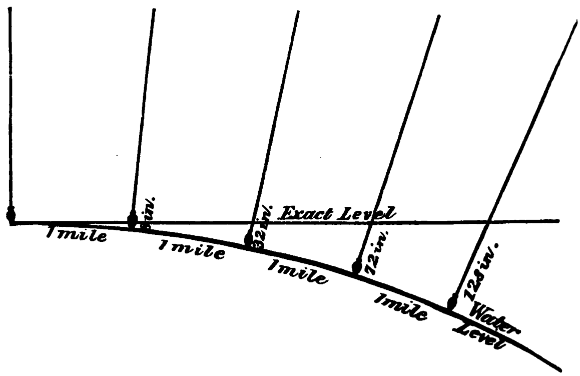

FIG. 48.—DEVIATION OF WATER-LEVEL FROM EXACT LEVEL.

The surface of water or level ground falls from a horizontal line 8 inches at the end of one mile, but 8 inches multiplied by the *square of* 2 at the end of two miles, and by the *square of* 3 at the end of three miles, etc.

Why are not the plumb-lines parallel in Fig. 48?

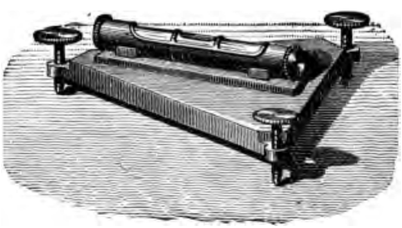

FIG. 49 —A SPIRIT-LEVEL.

146. Spirit-Level.—This very common instrument is a glass tube *almost* filled with alcohol, but with a small air-bubble left in it, and then sealed up air-tight. The tube looks to be perfectly straight, as in Fig. 49, but it is really slightly

[1] Do not forget to know clearly what *concave* and *convex* mean. You can remember that a concave surface is hollowed out like a cave, and that a convex one has just the opposite shape.

curved, as shown (but exaggerated) in Fig. 50. When the ends of the tube are level, the middle is the highest point, and the light bubble is found there. The spirit-level is constantly used by carpenters and other mechanics, and is

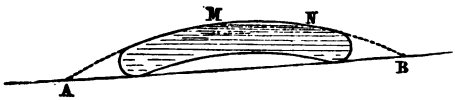

FIG. 50.—THE CURVE OF A SPIRIT-LEVEL (EXAGGERATED).

often attached to telescopes, and to surveying and other instruments.

Alcohol never freezes at natural temperatures, and is therefore the best liquid for filling levels.

147. Bodies in Water: three Important Laws.

Experiment 24.—Make a cube of wood[1] 5 centimetres (2 inches) on each side, weigh it, then let it float upon a vessel which was *full* of water. Weigh the water which ran over, and it will be found to be the same as the weight of the cube. Therefore,

I. *A body floating in water displaces its own weight of the water.*

When will the vessel weigh more, full of water, or with the wood floating in it? Try it.

Experiment 25.—Drive enough brads or tacks without heads entirely into the wood to sink it in water. Drop the cube into a vessel full of water. Catch the water which runs over in some vessel in which you can measure its volume. It will be found to be exactly 125 cubic centimetres (8 cubic inches). Therefore,

II. *A body immersed in water displaces its own bulk of the water.*

Could this principle be used to find the volume of an irregular solid, such as a bunch of keys or a watch-chain? Could you do it without making the water overflow?

Experiment 26.—Hold a stone by a string in the air, and afterwards in water; notice how much lighter it is in the water; or, more exactly, hang the weighted wooden cube by a thread to one arm of a

[1] Any piece of wood will do equally well for this experiment, but this cube will be most convenient for the succeeding ones, hence the recommendation. In order to make the experiment entirely satisfactory, the wood ought to be coated with varnish, oil, paraffin, or something of the sort, to keep it from absorbing water.

balance and weigh it. Then let it hang immersed in water and weigh it again. Its weight will be 125 grams ($4\frac{3}{8}$ oz.) *less*,—the weight of a cube of water 5 centimetres, or 2 inches, on each side. Therefore,

III. *A body immersed in water is lightened by the weight of its bulk of water.*

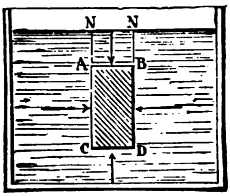

FIG. 51.

Let ABDC represent a solid block immersed in water. It is pressed *upward* at CD with a pressure equal to the weight of the column of water NCDN, and *downward* at AB by only the weight of NABN; therefore on the whole the block is pressed upward, or lightened, by the weight of the *difference* of these two columns, or ABDC.

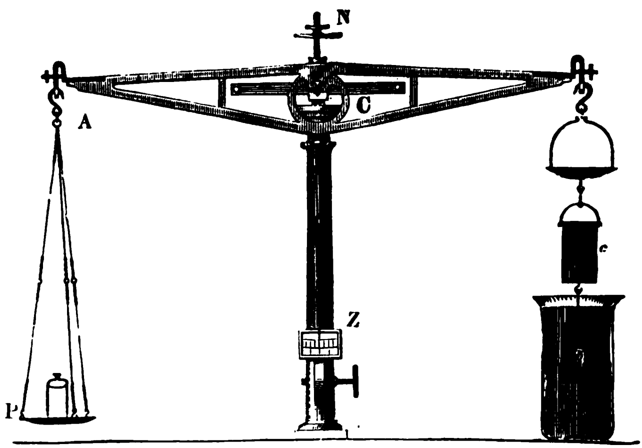

FIG. 52.—THE CYLINDER AND BUCKET EXPERIMENT.

Fig. 52 shows a piece of apparatus which illustrates this beautifully. The cylinder *p* is of solid metal, and fits into the bucket *c* exactly. The two are weighed at first with no water in the jar. Water is then poured into the jar to cover *p*, when it will be lightened, and the scale-pan *P* with the weights will fall. But if *c* be filled with water, the scales will balance again. Explain this.

148. **Floating Bodies.**—We see, then, that a body lighter *than water* floats because a *part* of it displaces enough

water to equal in weight the *whole* of the body. Material much heavier than water can be floated if thin and hollow. It is on this principle that iron and steel ships are made, which not only float but carry immense loads of freight.

149. **Stability of a Floating Body.**—A floating body is supported at many points, but as the supports are not rigid it is their *combined effect* only that supports the body. This combined effect is at the *centre of gravity of the water displaced*, which is called the *centre of buoyancy.* The centre of gravity of a boat with a solid cargo is always in the same place, but the centre of buoyancy shifts from side to side, in the direction in which a boat careens, and thus aids in quickly righting the boat.

It thus happens that a boat may be stable with the centre of gravity *above* the centre of buoyancy, if not too far above. This is shown in Fig. 53, in which G is the

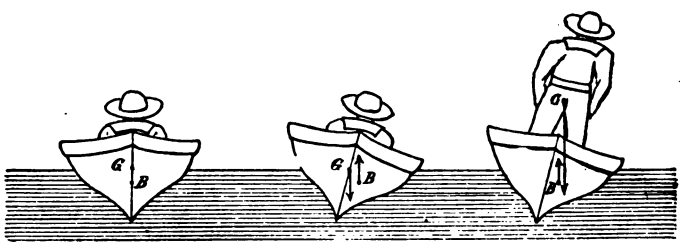

FIG. 53.—BOATS STABLE AND UNSTABLE.

centre of gravity, and B the centre of buoyancy. While the occupant sits down, any rocking of the boat shifts the centre of buoyancy more rapidly than the centre of gravity. In the second position the combined effect of the upward pressure at B and the downward pressure at G tends to right the boat. Two forces thus acting to *turn* a body are a "couple." Here the couple produce rotation about a point toward the middle of the boat from the centre of buoyancy. If the couple should tend to produce rotation about a point between the centre of buoyancy and the edge

of the boat, as when a boy stands up in a narrow canoe and careens it, the boat would overturn.

When the centre of gravity is *lower* than the centre of buoyancy, a vessel tends to right itself under any conditions. All sea-going vessels carry heavy cargo, or if this is not to be had they carry ballast, near the keel. Some "tank ships" carry oil in bulk. When such vessels careen in a storm the oil may run to the lower side and prevent the vessel from righting.

SPECIFIC GRAVITY.

150. **When we speak** of the weight of a *body* we refer to its mass, and denote it in pounds or kilograms. When we speak of the weight of a *substance* we refer to the intrinsic weight of the material, wherever found, and whether in large or small masses. This is really the *density* of the substance. (Art. 17.) Water being the standard of density, the subject is properly treated in this place.

By the definition (Art. 26) a cubic centimetre of water weighs a gram. If we carefully cut a piece of lead into a cube a centimetre each way, we shall find it weighs 11.4 grams. A similar cube of iron weighs 7.7 grams, and a cube of pine wood weighs half a gram. That means that lead is 11.4 times as heavy (or dense) as water, iron 7.7 times as heavy, and pine wood one-half as heavy. From this we derive the following definition:

151. **The Specific Gravity** of any solid or liquid substance is its density compared with the density of water.

152. **To find the Specific Gravity of a Solid.**—It is generally difficult to measure the volume of a solid directly. Two methods of finding specific gravity without measuring are illustrated by experiment.

Experiment 27.—Weigh a small stone. Carefully put it into a glass *full* of water. Weigh the water that runs out and divide into the weight of the stone.

Experiment 27*a*.—Take the same piece of stone and, suspending it by a thread from the pan of a balance, lower it into water until it is *all*

under water, as in Fig. 52, no matter whether the vessel containing the water is full or not. Now weigh again. The *loss of weight* is the weight of the water. Divide this into the weight of the stone. The results should be the same as in the previous experiment.

Illustration.—A piece of building-stone weighing 5 oz. is weighed in water and found to weigh only 3 oz. Its specific gravity is $5 \div 2 = 2\frac{1}{2}$.

The Decimal System of weights is the best for all purposes, but it is especially so for determining specific gravity and weights of masses derived from their specific gravities. *First*, there is no reduction to lower or higher denominations. If a body should weigh 2.47 grams in air, and .86 gram in water, we simply subtract, and obtain 1.61 grams as the weight of the water. A body of the same material weighing (Troy) 2 oz. 9 pwt. 10 gr. in air, would weigh 17 pwt. 5 gr. in water, and by compound subtraction we find 1 oz. 12 pwt. 5 gr. as the weight of the water. This must be *reduced* to be divided into 2 oz. 9 pwt. 10 gr. (Work out this example by both methods, carrying the work to two places of decimals.) *Secondly*, the specific gravity of a substance expresses the weight in grams of a cubic centimetre of it, the weight in kilograms of a cubic decimetre, and the weight in metric tons of a cubic metre. This follows from the definition of gram.

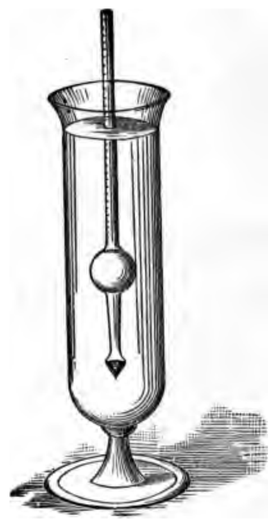

FIG. 54.—HYDROMETER.

In finding specific gravity, the precision of the balance and the kind of weights used make no difference in the result. A stick of pine, with a tin lid suspended from one end to hold weights, and hung by the centre of gravity *after the lid is attached*, is a good balance; and a pound or two of nails *all alike*, a good set of weights.

If a solid is lighter than water, press it under water, weigh or calculate the water displaced, and divide into the weight of the solid. If the glass is *full* to start with, weigh the water that runs over; if it is not full, measure the height to which it rises in the vessel, or better, use a cylindrical glass vessel graduated in cubic centimetres.

153. To find the Specific Gravity of a Liquid, we weigh a bulk directly and compare with water. Physical laboratories are supplied with a carefully-made flask which will

hold exactly either 1000 grains or 100 grams of distilled water. The first flask would hold 795 grains of very pure alcohol (sp. gr. .795). The second would hold 184 grams of pure sulphuric acid (sp. gr. 1.84).

If we have no specific-gravity flask, we may obtain the specific gravity of a liquid by its buoyancy.

Experiment 28.—Weigh a stone in air, in water, and in brine. From its *loss* in water and in brine, tell the specific gravity of the brine. Try it again, using lamp-oil instead of brine.

Hydrometers.—Fig. 54 shows the hydrometer, an instrument frequently used to test milk, alcohol, syrups, acids, etc. It is a glass tube weighted below with shot or mercury. The lighter the liquid the farther it will sink. A boy may make one of a stick of pine an inch square and a foot long, with melted lead poured into a hole at one end. Varnish it, mark off equal divisions of the length, and try it in water, also in the brine and oil of the last experiment.

SURFACE TENSION AND CAPILLARITY.

Experiment 29.—If two or more corks, sticks, or pieces of straw be floated on a vessel of water, they will soon be found *together*, or at the edge of the vessel. Furthermore, they come together, just at the last, with a rush, showing the presence of a very considerable force. If we examine each cork carefully as it floats on the water, we shall find the water extending up on the cork in a curve, as shown in Fig. 55. As the corks approach each other, the water-curves take hold of each other as it were, and, pulling on the corks, raise the surface of the water between them quite above the ordinary water-level. A long rope extending between two boats, with a man pulling at each end, does not come out of the water in the middle and tighten up as the boats approach each other, any more evidently than does this miniature water-surface between the corks, and the reason is the same. The water adheres to the cork, rises on its side, and a pull is communicated from particle to particle of the surface-water to the other cork, which shows the pull by its motion. Whether the corks float together, or to the sides of the vessel, depends upon which they are placed nearest to at first.

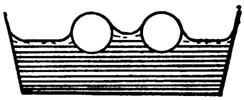

FIG. 55.—CORKS ON WATER.

154. **Surface Tension.**—This property which liquid surfaces have of communicating a pull or standing a strain is called Surface Tension. It is due to the fact that the molecules on the surface of a body of water have no molecules *above* to exert attraction on, as all those below the surface have, so they exert an *unbalanced* attraction, or rather have

an unbalanced attraction exerted on them downward and sidewise, which causes them to hold together on the surface layer with more than normal force. If a steel needle of considerable size be oiled and placed on a basin of water, it *floats* on account of the surface tension. (Fig. 58.) The water-spider (Fig. 59) walks on water because of surface tension.

155. **Capillary Attraction.**—The water rises around the corks of Experiment 29, because the attraction of the cork for the water (adhesion) is greater than the attraction of the molecules of water for one another (cohesion). This is true of many other substances besides cork.

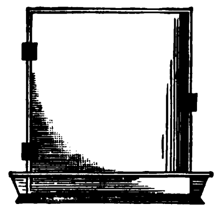

FIG. 56.—CAPILLARY ATTRACTION BETWEEN PLATES.

Experiment 30.—A pair of glass plates touching at the left-hand edge, and held apart at the right-hand edge by the thickness of a match-stick, show, on being dipped into water, the curve of Fig. 56.

Experiment 31.—If several very fine glass tubes be dipped into water, the liquid rises in them, the height being in proportion to the *fineness of the bore.*

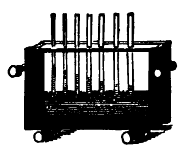

FIG. 57.—CAPILLARY ATTRACTION IN TUBES.

This attraction of solid surfaces for liquids is called capillary attraction (Lat. *capil'lus*, a hair), because it is shown so nicely in hair-like glass tubes.

Any substance that water (or any liquid) will *wet* exhibits capillary attraction, and we turn it to account and find it turned to account in many ways. It is capillary attraction that brings the moisture up from the damp earth to sustain vegetation in dry weather. It is capillary attraction that causes a sponge to absorb water, a blotter to absorb ink, a lamp-wick to draw up oil, a towel to dry your face and hands when they are wet. If a lamp-wick or rag have one end in a basin of water and the other hanging over the side of the basin, it will slowly drain all the water out of the basin; but any impurity in the water will remain in the basin.

Experiment 32.—Repeat Experiment 29, using two candles instead of two corks. They will never come together. They are not wetted, therefore no capillary attraction, therefore the surface tension does not draw them together.

It is because the needle is not wet that the surface tension keeps it from sinking, and because the feet and body of the water-spider are not wet he is enabled to walk on the surface of the water.

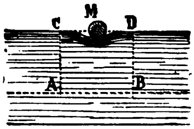

FIG. 58.—CROSS-SECTION OF A FLOATING NEEDLE.

FIG. 59.—INSECT WALKING ON WATER.

If the floating candles of Experiment 32 be examined carefully, it will be seen that the water, instead of *rising* where it meets the candles, as it did in case of the corks, is depressed, as in Fig. 58. This is the case when any solid is dipped into a liquid which will not wet it. The cohesion of the molecules is greater than their tendency to adhere to the solid. The water which would fill the trough C D, Fig. 58, weighs as much as the needle does, so that the needle *displaces its own weight of water*.

The mercury in a barometer-tube has a convex top. Such a tube should be about one-fourth of an inch in diameter, and the height taken at the *top* of the curve. (See Art. 172.)

Exercises.—1. A thousand-grain flask (Art. 153) will hold 900 grains of ammonia-water: what is the specific gravity of the ammonia-water?

2. A bottle weighs 200 grams. Full of water it weighs (bottle and all) 300 grams. Full of hydrochloric acid it weighs 320 grams. Find the specific gravity of the acid.

3. A stone balances 40 tenpenny nails in the air. In water it balances 24 nails, and in a solution of lye it balances 18 nails. Find the specific gravity of the lye. *Ans.* $1\frac{3}{8}$.

4. Why must bodies be *entirely immersed* in water in experiments for determining specific gravity?

5. A hydrometer of uniform size sinks 8 inches in water and $11\frac{1}{8}$ inches in ether. What is the specific gravity of the ether?

6. The above hydrometer sinks 6.4 inches in syrup. Find the specific gravity of the syrup. *Ans.* $1\frac{1}{4}$.

7. A piece of iron weighing 7 oz. is put into a glass full of water weighing 7 oz. After the iron is taken out the glass of water weighs only 6 oz. Find the specific gravity of the iron. *Ans.* 7.

8. A graduated glass contains 220 cubic centimetres of water. An egg weighing 44 grams is dropped into the glass, when the water rises to 260 cubic centimetres. Find the specific gravity of the egg. *Ans.* 1.1.

9. A dam-breast is 1000 metres long, it slopes from the surface of the water to a depth of 12 metres, and the breadth of the part under water, measured slopingly, is 15 metres: what weight of water in kilograms rests upon the breast? *Ans.* 54,000 cubic metres = 54,000,000 kilograms.

10. How far out at sea could a light-house 200 feet high be seen? *Ans.* 17.32 miles. How far off could it be seen from the top of a vessel's mast 100 feet high? *Ans.* 29.56 miles. (How far towards the light-house could the surface of the water be seen from the top of the mast? Then, if one's eye were placed *there*, how much farther would it be to the light-house?)

11. Why is it easier to lift a stone under water than to lift the stone in the air?

12. The specific gravity of quartz (commonly called flint) is about 2.5. A boy can lift 120 pounds: how heavy a quartz rock can he raise to the surface of a creek? *Ans.* 200 pounds.

13. A piece of copper weighs 1100 grams, and in water it weighs 975 grams: find its specific gravity.

14. A piece of wood weighs 3 ounces; a bit of lead weighing 2 ounces in water will just keep the wood totally immersed: find the specific gravity of the wood. *Ans.* .6.

15. A water-tight box is 6 inches long and 3 inches wide. A bunch of keys raises the water in it $\frac{1}{4}$ inch: what is the volume of the keys? If your hand raises the water $\frac{1}{2}$ inch, what is its volume?

16. A cylindrical cork floats vertically with 1 inch above the water and $\frac{3}{10}$ of an inch below: find the specific gravity.

17. The specific gravity of a body is 17: find the volume of 89 ounces of it.

18. A cup when empty weighs 6 ounces; when full of water it weighs 16 ounces; when full of coal-oil it weighs $14\frac{3}{4}$ ounces: find the specific gravity of the coal-oil.

19. A wooden hydrometer, 1 inch square, sinks 9 inches in water, but 11 inches in oil: find the specific gravity of the oil.

20. A boat in a river displaces 8000 cubic feet of water; on reaching the ocean it rises so as to displace only 7800 cubic feet: find the specific gravity of sea-water and the weight of the boat. *Answers*, 1.026–. 250 tons.

21. The specific gravity of cork is .24: what is the volume and what the weight of a cork that must be attached to a piece of lead weighing 5 ounces in water, in order that both in the water may weigh 0?

22. A flask weighs 960 grains, and it will hold 2000 grains of water. Some powdered chalk weighs 50 grains in the air. When placed in the flask and the flask filled up with water, its weight is 2990 grains. Find the specific gravity of the chalk.

SECTION II.—HYDRAULICS.

156. Flow of Liquids through Openings.—We have learned in Art. 96 that, discarding the resistance of the air, a body which has fallen from any height has just the velocity with which a body would have to be sent upward to reach that height. And we also know that a fountain, if the resistance of the air and friction did not hinder it, would rise to

the level of the water in the reservoir. It must be true, then, that *water flows out of an opening with the same velocity that it would acquire in falling from the level of the water to the opening.*

Art. 90 gives us the means of finding this velocity. For $v = gt$, and from the formula $s = \frac{1}{2}gt^2$ we find $t = \sqrt{2s \div g}$, whence $v = \sqrt{2gs}$. The velocity, then, varies as the *square root* of the depth. In order that the liquid may flow out

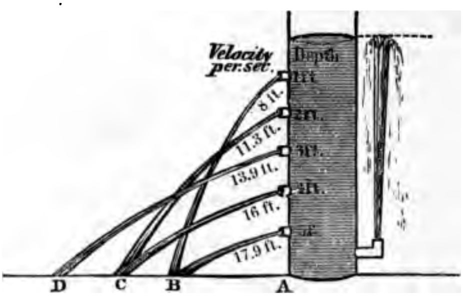

FIG. 60.—VELOCITY OF JETS.

twice as fast, the second opening must be 4 times as deep as the first, and 9 times as deep if it is to flow 3 times as fast.[1]

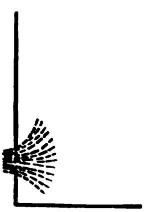

FIG. 61.—FLOW OF LIQUIDS THROUGH AN OPENING.

If an opening be made in the side or bottom of a vessel containing water, the stream which runs out will grow narrower for a little way after it leaves the opening, and then spread out again. The narrowest part of the stream is called the *vena contracta* (Latin, contracted vein). Its cause may be seen by scattering a little chalk-dust in the vessel, which will be carried along by the currents of water and show that these currents rush towards the opening from all directions, as shown in Fig. 61. And they keep on converging a little way beyond the opening and make the *vena contracta* there. On this account the quantity of water which ought to be discharged at a certain opening

[1] Before the invention of clocks, time was almost universally measured by the descent of water in a tall vessel which had a small opening at the bottom. This was called a clepsydra. If the opening is

is never reached in practice, nor is the calculated velocity ever quite reached, on account of the friction. The *range* of the spouting liquid may be found by multiplying the velocity of discharge by the number of seconds which it has to flow before striking the ground. This last is the same as the time in which a body would fall to the ground from the height of the opening. For example, in Fig. 60 the water flows from the middle orifice with a velocity of 13.9 feet per second. As this orifice is 3 feet from the ground, the time of falling from it to the ground is found by Art. 156 to be .43 second, and the range is 13.9 feet multiplied by .43, or 5.977 feet. So the range is determined for a liquid spouting horizontally from any opening.

It is thus found that if various openings be made in the side of a tall vessel sitting on a level surface, the range is greatest from that orifice which is midway between the top of the water and the level surface on which the range is measured, and that the range of any two jets equally distant from the middle one will always be the same.[1] Let the student work out the ranges of the various jets shown in Fig. 60, and also try the experiment, using a good flour-barrel with three smooth holes in the side, one in the middle, one above, and one below, each about 8 inches from it. They are better with short pieces of tube fitted into them. These are universal laws, and can be rigidly demonstrated.

157. **Flow through Pipes.**—A very short pipe discharges more water from a vessel than an opening in the side of the vessel without the pipe, for the water tends to follow the side of the pipe, and the *vena contracta* is not so small. But a long pipe greatly retards the flow. A long hose-pipe

made just large enough to empty the vessel, after it has been filled 1 inch deep, in an hour, it must be 4 inches deep to run 2 hours, 9 inches deep to run 3 hours, 16 inches deep to run 4 hours, etc. Or the lowest hour-mark would be 1 inch high, the next 3 inches above that, the third 5 inches above that, etc., the spaces between the hour-marks increasing as the odd numbers. This depends upon the principle of falling bodies, derived from Art. 90.

[1] The student may find, on working out problems for openings equal distances above and below the middle of a vessel, that the results will not exactly agree in the second decimal places. This is because the decimal places in the velocity and time of fall were not carried out far enough. If carried out, they will agree exactly. Will the resistance of the air interfere with the above conclusions?

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illustrates this well. Bends in a pipe check the flow very much, and a sharp corner much more than a curved bend.

158. **Flow of Streams.**—The friction of the sides and bottom retards streams very much, otherwise all our streams would be raging torrents. Small streams may fall rapidly, but the great rivers of the world have a fall of only a few inches per mile, and flow from 2 to 5 miles per hour.

The Mississippi[1] from its source to its mouth has an average fall of but 7 inches to the mile, and in the lower half of its length of about half of this. In the last 3000 miles of its course the Amazon falls less than 1 inch per mile.

159. **Waves.**—Throw a pebble into a still pond or a puddle of water, and a wave is made which runs to the shore. The most important fact to be noticed about this wave is that, while the wave moves forward, *the particles of water do not move forward, but each particle in its turn simply moves up and down.* This can be seen by watching a chip floating in the water at some little distance from the edge. The chip will rise and fall with the water, but will not come to the shore. If, however, the chip be only a few inches from a sloping edge of the pond, it will presently be driven ashore, for the water growing shallower causes some forward motion along the shore.

It may not be easy to see how the wave can move forward while the water only moves up and down. If you will take a piece of rope and tie one end to a nail, or let a

[1] A question which is both interesting and profitable is often asked as to whether the Mississippi flows up-hill. As this river is in the northern hemisphere and flows from north to south, on account of the bulging out of the earth as we approach the equator (or its flattening towards and at the poles), its mouth is $2\frac{1}{2}$ miles farther from the centre of the earth than its source, and is therefore that much higher than the source. But the mouth of the river is on a much larger circle of latitude than the source, and must therefore revolve through a considerably larger circle in the twenty-four hours. This causes greater centrifugal force at the mouth, which compensates for its greater distance from the centre of the earth.

companion hold it, and, holding the other end in your hand, give it a jerk, just such a wave as has been described above will run along the rope, while each particle of the hemp has moved only up and down. And very likely you have often seen a wave, caused by the wind, run across a field of grass or standing grain, which you see must be caused in this way. The great waves of the ocean, sometimes thirty feet high, are caused by the action of the wind upon the surface of the water. Like the waves in the pond, they are, out at sea, only upward and downward motions of the water; along a sloping shore they get a forward motion, and become *breakers*. The highest part of a wave is called its *crest*. The hollow is the *trough*. The distance from crest to crest, or from any part of a wave to the corresponding part of the next one (called corresponding *phases*), is the length of the wave.[1]

If two waves were to meet each other so that the two crests met, one would be piled upon the other, and a crest higher than either would be formed. But if the crest of one meets the trough of the other it will fill the trough, and, if the waves are of the same size, smooth water will be the result.

WATER MACHINES.

160. **Water-Wheels.**—These familiar machines are of great value. In all cases their power is caused by water falling from a higher to a lower level. In the dam, or head-race,[2] which may be twenty feet above the tail-race,[2] the water has *potential* energy. In falling, its energy is *actual*, and this it communicates to the wheel, and thence to the machinery.[3] Four kinds of water-wheels are usually described.

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[1] It is important that what is said here about waves should be clearly understood, for they play an important part later in the book.

[2] Find out what these are, if you do not know.

[3] Does the water ever get back to the dam again?

161. **The Overshot-Wheel.**—This is probably the most common of all the water-wheels. As shown in Fig. 62, in the circumference of the wheel are what are called buckets, into which the water runs from above (hence its name), and the weight of the water in the buckets turns the wheel. Some of the objections to the overshot-wheel are its cumbersomeness, the loss of water from the buckets on their way down, and its liability to freeze up in winter in Northern latitudes. Yet very many manufacturers still prefer it to any other water-wheel. Under favorable circumstances, overshot-wheels may utilize 75 per cent. of the potential energy of the water.

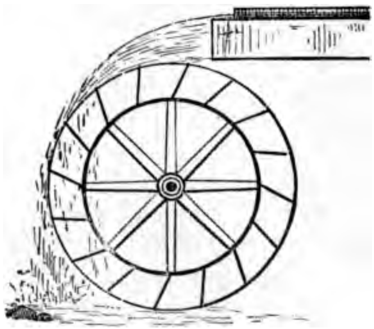

FIG. 62.—OVERSHOT-WHEEL.

162. **The Breast-Wheel.**—This wheel is shown in Fig. 63. It is sometimes used where there is but a short fall of water. Both the weight and the momentum of the water aid in producing the power. Under the best circumstances, the breast-wheel utilizes 65 per cent. of the water-power.

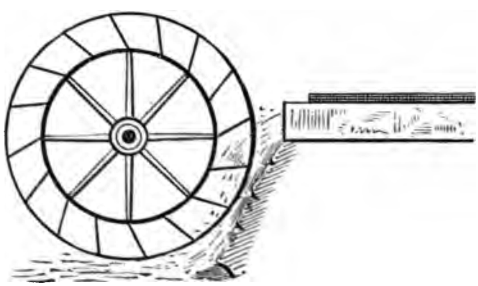

FIG. 63.—BREAST-WHEEL.

163. The Undershot-Wheel.—This is the most inefficient of all the water-wheels, generally utilizing only about 30 per cent. of the power. It is only adapted to streams having a strong current and but little fall, and is seldom used at all.

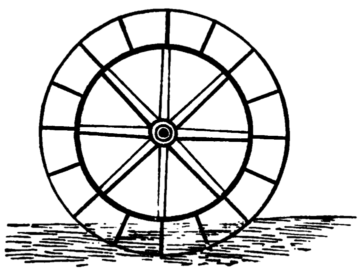

FIG. 64.—UNDERSHOT-WHEEL.

FIG. 65.—TURBINE-WHEEL.

164. The Turbine[1] Water-Wheel.—This is a water-wheel of modern invention, and was first used in France. It is an iron wheel with curved paddles, as shown in Fig. 65. This wheel is set into an iron case *with its axis vertical.* Fig. 66 shows the case with the wheel inside but hidden from view. The water passes inward through the openings in this case, and strikes the paddles of the wheel within, thus driving the wheel around. After giving all its force to the wheel, the water drops through a large opening in the bottom of the case and flows away. Unlike the first three wheels, the turbine revolves *horizontally,* not vertically.

The encased wheel is often set in an *outer* iron case, as seen in Fig. 67. This is attached to a wooden or iron tube (Fig. 68), which brings the water from the head-race.

[1] *Pronounced* tur′bin.

Turbine-wheels are all comparatively small. They are made as small as 1 foot or less in diameter, and are very seldom more than 6 feet in diameter. The turbine-wheels, being always entirely under water, do not freeze up in winter, and they utilize more of the power of the water, reaching 80 or more per cent. of it. On these accounts many of them are now in use, and they seem likely to supplant almost entirely the other forms of water-wheels.

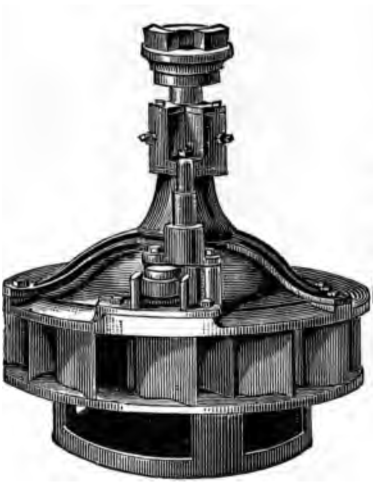

FIG. 66.—TURBINE-WHEEL IN ITS INNER CASE.

FIG. 67.—THE OUTER CASE.

165. **The Hydraulic Ram.**—This is a machine in common use for raising water. The way in which it works may be explained by reference to Fig. 69. A is a large supply-pipe leading down from a spring or other constant source of water. At C is a valve which falls down of its own weight and leaves an opening above it. When the water begins to flow through A, it escapes at C, but quickly acquires velocity enough to raise the valve there, and, by pressing it against the top, to close that opening. As the water in A *is running* with considerable momentum, and as the water

cannot be compressed in the lower part of the pipe (Art.

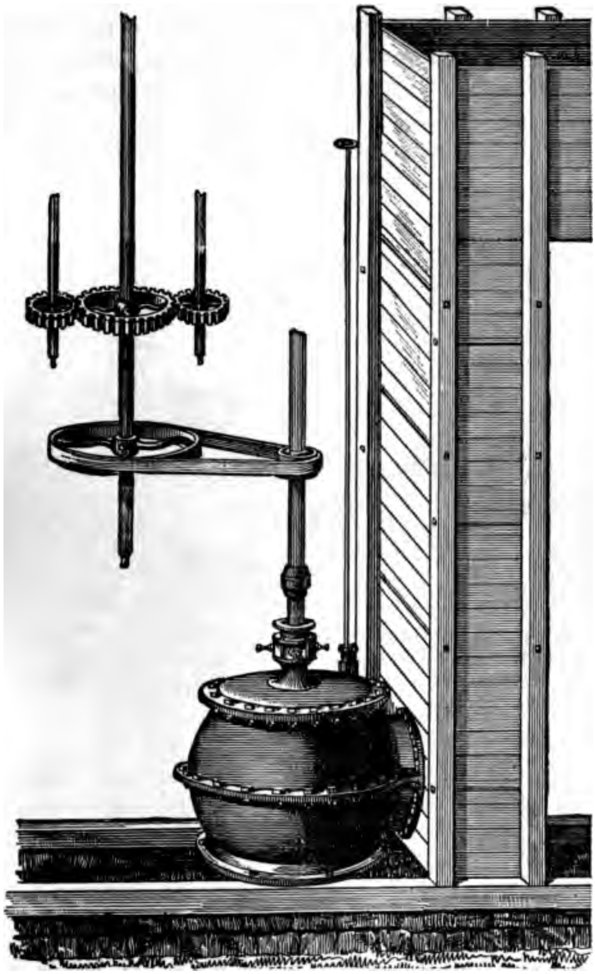

FIG. 68.—THE TURBINE-WHEEL AT WORK.

132), it lifts the valve B and rushes up into the air-chamber D, compressing *the air into* the upper part of the air-cham-

ber until the flow ceases. Then the valve C falls again, and the same process is repeated. The compressed air in the air-chamber, by constantly pressing upon the water below it, drives the water up the small pipe EF in a constant stream. This machine will work for months without any attention, but the water gradually absorbs and carries off the air in the air-chamber, so that occasionally a new

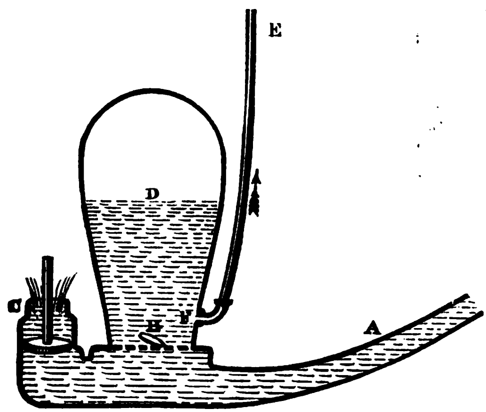

Fig. 69.—The Hydraulic Ram.

supply must be admitted. The pipe A need have only a few feet of fall, and water may in this way be raised through EF to a considerable height. The repeated shock and noise caused by the lifting of C has been thought to resemble the butting of a ram, hence the curious name of this machine.

166. **Barker's Mill.**—This scientific toy is shown in Fig. 70. It consists of an upright tube, *c*, near the bottom of which are two smaller tubes extending out on opposite sides of the upright tube; near the ends of these, *but on opposite sides*, are two small openings. The pressure from the column of water in *c* is relieved at the openings, but it *presses against* the sides of the tubes opposite the openings;

and hence moves the machine around in that direction, or opposite to the direction in which the water spouts.

The joints of a cane fishing-pole will furnish excellent material, in the hands of an ingenious boy, to make a Barker's Mill.

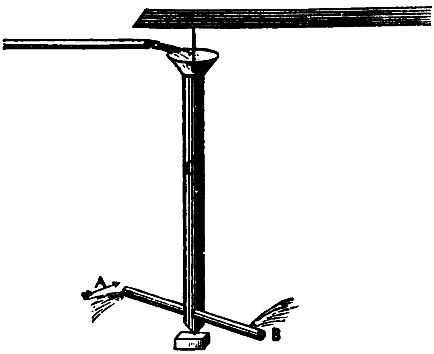

FIG. 70.—BARKER'S MILL.

Exercises.—1. Verify the velocities of the different jets in Fig. 60.

2. Find the velocity of a jet of water through an opening 10 feet below the surface; 20 feet below.

3. Find the range in each case in the preceding problem, if the surface of the water in the vessel be 30 feet from the ground.

4. Making no allowance for the *vena contracta*, how much water would be discharged through the lowest opening in Fig. 60 in 1 minute if the opening is 1 inch square and the surface of the water be kept at the same height?

Solution.— 17.9 feet = 214.8 inches, velocity per second.

$214.8 \times 60 = 12{,}888$ inches, velocity per minute.

As the jet flows 12,888 inches per minute, a column of water 1 inch square and 12,888 inches long flows out in 1 minute, that is, 12,888 cubic inches. As there are 231 cubic inches in a gallon,

$$12{,}888 \div 231 = 55\tfrac{61}{77} \text{ gallons.}$$

5. The area of the *vena contracta* is usually about $\frac{5}{8}$ of the orifice: supposing this to be the true cross-section of the stream, what would be the flow per minute in Exercise 4? *Ans.* $34\frac{67}{77}$ gallons.

6. If in Exercise 2 each opening is a circle 1 inch in diameter, how many gallons will flow out of each in 1 minute, no allowance being made for the *vena contracta*?

7. What would be the discharge in Exercise 6 if the *vena contracta* be allowed for as being $\frac{5}{8}$ of the area of the orifice?

8. Why is a stream swifter in the middle than near the banks?

9. Why does the water of a stream flow so much faster during a flood than usual?

10. A stream discharges 1800 cubic feet of water per minute upon an overshot-wheel 12 feet in diameter. What horse-power should the wheel give? *Ans.* 30.7.

11. Ninety cubic feet of water per second are discharged against the middle of a breast-wheel 10 feet in diameter. What horse-power should it develop? *Ans.* 33.2.

12. A turbine water-wheel uses 2500 gallons of water per minute. The fall in the pipe from the head-race to the tail-race (surface of each) is 18 feet. What horse-power should it develop? (Call a gallon of water 8 pounds.) *Ans.* 8.7.

SUMMARY OF CHAPTER III.

In liquids there is perfect freedom of motion among the molecules.

On this account they transmit pressure perfectly, and equally in all directions.

On this account, also, the pressure of a liquid on a unit area of the vessel containing it is directly proportional to the *height* of the liquid above the point considered, without any reference to the *quantity*.

On this account, also, the free surface of a liquid at rest is always at right angles to the direction of gravity,—*i.e.*, *level*.

The transmission of pressure by liquids finds useful application in the hydrostatic press. It causes the rise of water in pipes, and gives us many of the phenomena of fountains, artesian wells, etc.

The water-level is a curve, the shape of the earth.

A body immersed in water is buoyed up by an amount equal to the *weight* of the water displaced.

The specific gravity of a body is its weight per unit volume compared with water.

The particles on the free surface of a liquid have an attraction for one another in excess of the attraction between particles under the surface.

This gives rise to surface tension, which supports light bodies *entirely above* the liquid, which draws wet floating bodies together, etc.

Capillary attraction is noticed when the surface of a body in contact with a liquid has an attraction for the liquid greater than that of the liquid molecules for one another.

The velocity of a spouting liquid is the same as that of a body falling freely from the surface of the liquid to the orifice.

In a wave, the particles of water move only up and down.

Of all forms of water-wheel, the turbine is the most effective in turning to practical use the potential energy of the water in the head-race.

CHAPTER IV.

GASES.

167. **Definition and Properties.**—As we have before learned (Art. 33), gas is that form of matter in which the molecules have a repellent action upon one another. A gas will expand indefinitely if it has room to do it in. A thimbleful of air, if put into an absolutely empty room, would fill the whole room. The force with which a gas tries to expand is its *tension.*

All liquids, and even some solids, are constantly, though perhaps slowly, changing to gas, which disappears by spreading itself through the air. This is called *evaporation*, and the gases into which the solids or liquids turn are called their *vapors.* By the application of heat almost every solid has been liquefied and then changed to vapor or gas. On the other hand, all the gases have by cold and pressure been changed into liquids or solids.

Until 1877, air and several other of our most common gases resisted all efforts to change their gaseous form; but in that year two European scientists, by means of great cold and enormous pressure, liquefied or solidified all of those gases which were formerly called permanent.

168. **Compressibility of Gases.**—We found that liquids were almost absolutely incompressible. Gases, on the contrary, are easily compressed.

Experiment 33.—Press a tumbler, top down, into a basin of water. As it is pushed deeper, the water can be seen to rise somewhat in the mouth of the tumbler. The pressure of the water is compressing the air. The resistance you feel is the tension of the compressed air.

169. **Mariotte's**[1] **Law.**—Fig. 71 shows a piece of appa-

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[1] **Mă-re-ot′** (1620–1684), a French scientist.

This law was first discovered by an Irish scientist, Robert Boyle

ratus used for making more careful experiments in compressing air. A little mercury is poured into the open end of the glass tube, and the air from the short end of the tube is allowed to escape by tilting the tube until the mercury stands on a level in both arms at *a*. The air in the short arm is now at its natural density, and is pressed upon only by the weight of the atmosphere itself. This weight is equal to about 30 inches of mercury, as we shall see in the next article. More mercury is now poured into the long arm, until it is about 30 inches higher there than in the short arm, when the air in the short arm (*ab*) will be found to be compressed into *one-half* its former bulk (*mb*). There is double the pressure upon it (one atmosphere of air and one of mercury), which has compressed it one-half. If one column be made 60 inches higher than the other, the air in the short arm will be compressed into the upper *third* of *ab*; it is pressed down by *three* atmospheres. 90 inches of mercury (making with the air four atmospheres) will compress the air in the short arm into *one-fourth* of its original bulk. Hence we see that *the bulk of a quantity of air is decreased just as the pressure upon it is increased.* This law is substantially true of all the gases.

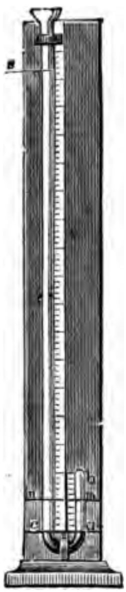

FIG. 71.—APPARATUS ILLUSTRATING MARIOTTE'S LAW.

Questions.—When the mercury is 30 inches higher than *c*, is it 30 inches higher than in the short arm?

If *ab* is 6 inches, how much above *c* will the long column reach when 30 inches higher than the short one? *Ans.* 33 inches.

How many inches of mercury must be poured in to raise it as above? *Ans.* 36 inches.

What will be the answers of the last two questions if the mercury in one tube is 60 inches higher than in the other?

(1626–1691), but was afterwards independently discovered by **Mariot** and hence usually goes under his name.

170. Column of Mercury supported by the Air.—Experiment 34.—Take a glass tube, 1 yard long, $\frac{1}{4}$ or $\frac{1}{8}$ of an inch in diameter, one end of which is closed, fill it with mercury, place the finger over the open end, and invert it, as shown in Fig. 72. Lower the tube until the open end is covered by the mercury in the pan below, then remove the finger. The mercury in the tube will sink until it is about 30 inches high, then it will stand there, being just balanced by the pressure of the air upon the surface of the mercury in the basin. *We have found that a column of mercury 30 inches high weighs the same as a column of air of the same thickness, extending from the surface of the earth to the top of the atmosphere.*[1]

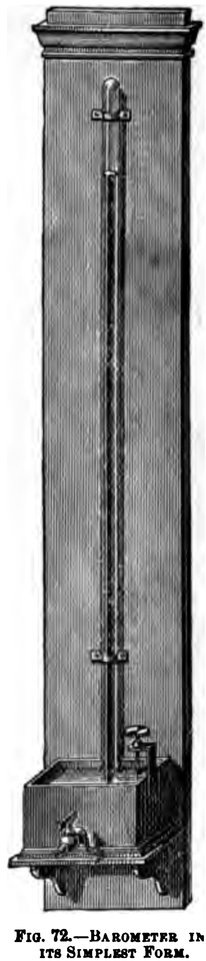

FIG. 72.—BAROMETER IN ITS SIMPLEST FORM.

When proper precautions have been taken to have the mercury pure and to remove all bubbles of air from the tube, the space above the mercury is almost a perfect vacuum. But yet there is a little vapor of mercury there. An absolute vacuum has never been made.

Why does the experiment not show that the column of mercury balances (and therefore weighs as much as) a column of air as large around as the basin? (See Art. 134.)

171. The Barometer.—If the glass tube and the basin of mercury just described be enclosed in a suitable case, and a scale of inches and fractions be made on a part of the upper end of the tube, we have a *barometer*, an instrument which will indicate the changes in the pressure (*i.e.*, the weight) of the air at that place, which makes it a very important instrument.

172. Height of Mountains measured with the Barometer.—When Pascal heard

[1] The height of the column of mercury may vary a little from 30 inches, showing that the weight of a column of the atmosphere

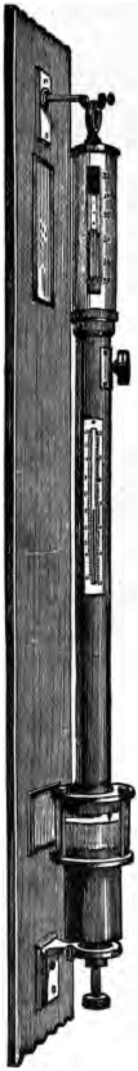

FIG. 73.—THE MERCURIAL BAROMETER.

of the experiment described in Art. 170, he said that if it was the weight of the air that held the mercury 30 inches high in the tube, were he to carry the basin and tube to the top of a mountain the mercury would fall below 30 inches, for there would not be so much air above it there. It was tried, and, as Pascal expected, as the tube was taken up the mountain the top of the column of mercury slowly went down, a convincing proof that it was the weight of the atmosphere which was supporting the mercury. Barometers are now very commonly used to measure the heights of mountains. For low mountains the mercury falls 1 inch for about every 900 feet of height. At a height of 3½ miles the mercury is 15 inches high.[1] Half of the atmosphere is therefore within 3½ miles of the surface of the earth.

173. The Barometer and the Weather.—The most common and valuable use of the barometer is to enable us to foretell the weather: hence it is often called a weather-glass. Any sudden change in the height of the mercury is almost always followed by a storm, and usually it *falls* rapidly before a

[1] The following table shows the height of the mercury at different distances above the earth:

HEIGHT ABOVE THE EARTH.	HEIGHT OF MERCURY.
1 mile	24.7 inches.
2 miles	20.3 "
3 "	16.7 "
4 "	13.7 "
5 "	11.3 "
10 "	4.2 "
15 "	1.6 "
20 "	1 inch (or less).

storm. This will be explained and more fully discussed in the chapter on Meteorology.

174. The Aneroid Barometer.—Fig. 74 shows the aneroid barometer, very different from the mercurial barometer, and much used now. It is a thin metal box, from which the air is partly exhausted and it is then made air-tight. The top of the box is pressed down more or less, according as the pressure of the atmosphere varies; this, by means of levers, causes a hand to move back or forth, which indicates the pressure. In the figure the metal box is seen within the outside case and behind the levers. It is graduated by comparing it with a mercurial barometer. The aneroid barometer is very convenient to carry and use, for it is sometimes made no larger than a watch. It is also

Fig. 74 —The Aneroid Barometer.

very delicate, but is liable to get out of order, and should frequently be compared with a mercurial barometer.

THE ATMOSPHERE.

175. **Composition of the Atmosphere.**—The atmosphere is composed mainly of two gases,—oxygen and nitrogen. These gases are not chemically united in the atmosphere, as oxygen and hydrogen are in water, but are simply mixed together in the proportion of four parts of nitrogen to one of oxygen. There is always vapor of water also in the atmosphere, as well as small quantities of other gases.

176. **Height of the Atmosphere.**—The height of the atmosphere is unknown. From calculations depending upon the duration of the twilight it was formerly supposed that the atmosphere was about 45 miles high. But this only proved that if there were air above that, it was not dense enough to cause[1] twilight. And recent observations of meteors[2] (shooting-stars) show that the atmosphere is at least 100 miles high. One-half of the whole, however, is within the first 3½ miles, and the upper part must be excessively rare.

177. **Weight of the Atmosphere.**—The atmosphere must weigh as much as an ocean of mercury covering the whole earth to a depth of 2½ feet. This is almost six quadrillion tons.[3] The air in a room 25 feet long, 20 feet wide, and 10 feet high weighs nearly 400 pounds.

178. **Pressure of the Air.**—A column of mercury 1 inch

[1] Twilight is the reflection of the sun's light from the upper part of the atmosphere. (Sharpless and Philips's Astronomy, p. 116.)

[2] Meteors, or shooting-stars, are small solid particles of matter moving in orbits around the sun. When these strike our atmosphere their velocity is so great that the heat produced by the blow burns them up, and it is the flash of this burning that we see. The observations referred to above show that some of them begin to burn 100 miles or more high: hence the atmosphere must extend to that height. (See Astronomy, chapter viii.)

[3] Verify this, taking 13.6 to be the specific gravity of mercury.

square and 2½ feet high weighs about 15 (14.7) pounds. Therefore the atmosphere everywhere presses down with a force of 15 pounds to the square inch. And, as is the case with water, this pressure is the same in all directions.

Everything about us is subjected to this enormous pressure. The average human body has a surface of about 2000 square inches, and therefore sustains a pressure of 15 tons. We are conscious of no downward pressure, because the air beneath presses us up just the same. And the human body, largely filled with liquids and air, is firm enough to resist the crushing pressure of 15 pounds to the square inch when distributed all over it.

179. **Experiments with the Pressure of the Air.**—**Experiment 35.**—Dip a tumbler under water in such a way that all the air may escape and it shall be full of water. Raise the tumbler partly out of the water, bottom upward, keeping the edge under water. Is the part of the tumbler above the water empty? Explain.

Experiment 36.—Fill a tumbler full of water. Cover the top with a card or piece of heavy paper, and, pressing this tightly against the top, invert the tumbler. Remove the hand from the card, and the upward pressure of the air will hold the card against the inverted tumbler and keep the water in it.

Experiment 37.—Make a "sucker" by taking a round piece of thick leather, fasten a string to the middle of it, wet it, and press it tightly against a brick or flat stone. As the air cannot get under the sucker, the downward pressure holds it to the brick, so that both may be lifted up by the string. Suppose the sucker stuck perfectly air-tight and had a surface of 4 square inches, how heavy a stone could be picked up with it?

Experiment 38.—Fig. 75 shows a pipette; the opening at the bottom is very small. Fill it with water and cover the upper opening with the finger, the water will not run out; remove the finger, the water will run or drop out. Why? This is much used for dropping small quantities of liquids.

Fig. 75.—Pipette.

Cupping.—Physicians, in treating certain diseases, sometimes press a cup to some part of the body and exhaust part of the air from it, either by sucking it out through a tube in the bottom of the cup, or by the burning of a bunch of paper which has been put into the bottom of the cup and set on fire before it was applied to the body. The skin and flesh are sucked up into the tumbler. This shows what an outward press-

E g

ure the body has, in order to withstand the enormous pressure of the air. (Ask your family physician to tell you all about cupping, so that you can answer your teacher's questions about it.)

180. **Stream of Air meeting a Surface.**—When a current of air strikes a surface, it does not bound off, according to the law of incidence and reflection, but follows along the surface. This is due to the adhesion of the air to the surface, and to the resistance of the surrounding air.

Experiment 39.—Blow obliquely against a wall, and while doing so hold a lighted candle so that the current would strike it were the angle of reflection equal to the angle of incidence. The flame will not be disturbed. Then hold the candle close to the wall beyond the place where the current strikes. The flame will be much disturbed, and may be blown out.

Experiment 40.—Bend a quarter of an inch of each end of a card at right angles to the card. Set the card up on these ends, as legs, upon a table, and try to blow the card over by blowing against the table under the card, with the intention of making the air rebound against the under side of the card. The air will not follow the angle of reflection, but along the table.

Experiment 41.—Take a small bent tube of glass, push one end just through a wide cork, or a piece of wood, so that the cork forms a little platform about the end of the tube. Put a pin through a card, and lay the card upon the cork, letting the pin run into the tube. Now blow into the other end of the tube. The card will not be blown off, but will stick tight to the cork, and, if turned upside down, will stay there as long as the blowing lasts; when that stops it will fall off. The air flowing out in all directions between the cork and the card produces a partial vacuum there, and the pressure of the air on the other side of the card causes it to stick closer. A common spool is a good substitute for the tube and cork.

181. **Buoyancy of the Air.**—All bodies in the air are buoyed up by it, just as they are when in water, and are of course lightened by the weight of the air displaced. This is about 1 ounce for each cubic foot of the body's bulk, and is not therefore noticed except with very light substances, such as feathers and the like.

182. **Balloons.**—These are huge bags of silk, made air-tight by varnish, and filled with hydrogen or, more commonly, with common illuminating gas. As either of these is much lighter than air, the balloon will ascend and carry considerable weight with it. In 1862, Mr. Glaisher (glā'-

sher), of England, ascended in a balloon to the enormous height of 35,000 feet, or nearly seven miles.

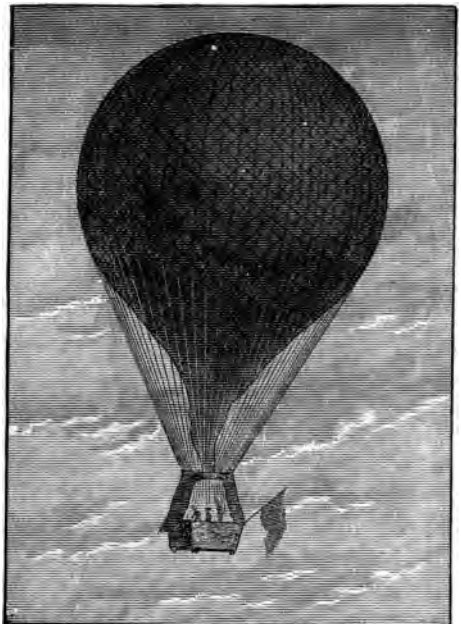

FIG. 76.—BALLOON.

PNEUMATIC MACHINES.

183. **The Bellows.**—The common hand-bellows is made of two tapering boards, joined together around the edges by flexible leather, and having a nozzle at one end. An opening in one of the boards is covered on the inside with a flap of leather fastened only at one end. This is a *valve;* it opens freely inward. When the sides of the bellows are pushed apart, the air pushes the valve inward and rushes in. But when the sides are brought together, the air pushes the valve tight against the side, and, thus closing that opening, must escape through the nozzle. The stream of air is not continuous.

Blacksmiths use an improved bellows, which gives a continuous stream of air. When one lets go of *a*, the lower board falls and the air pushes the valve *v* up and rushes in. When *a* is pushed down and *bc* raised, *v* closes and the air is forced through *v′* into an upper chamber. Upon this there are weights which constantly force the air out of the nozzle.

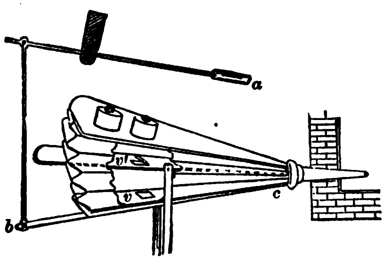

FIG. 77.—BLACKSMITHS' BELLOWS.

184. The Air-Pump.—This very useful machine was invented by Otto Guericke[1] about 1650. Fig. 78 gives a complete view of one of the simpler forms of the machine, and Fig. 79 shows the inside of one. In the common ones the rod running up from S′ is wanting. *ab* is a brass cylinder, called the *barrel*, in which an air-tight piston, *p*, moves up and down. When *p* is raised from the bottom of the cylinder, a vacuum is formed below it, and the tension of the air in the receiver E causes it to rush along the tube below, to push up the valve S′, and to fill the cylinder with rarefied air. When the piston is pushed down, S′ falls, and the air pushes S up in order to escape. One barrelful has been pumped out of the receiver. The next time a barrelful of rarer air is taken out, and that left in E is rarer. This can be kept up until the air in E is very rare, until it is so rare that its tension is too feeble to lift the valve S′, but it is evident that it can never be entirely exhausted.

Some of the more expensive air-pumps have the rod shown in Fig. 79, by means of which the piston opens and closes the valve S′. As seen in the figure, the rod passes through the piston, fitting in it rather tightly. When the piston is pushed down, the rod sticks fast

[1] Otto von Guericke (fon ga′rik-eh), a German natural philosopher, 1602–1686.

in the piston until S′ is pushed down, then the piston slips down

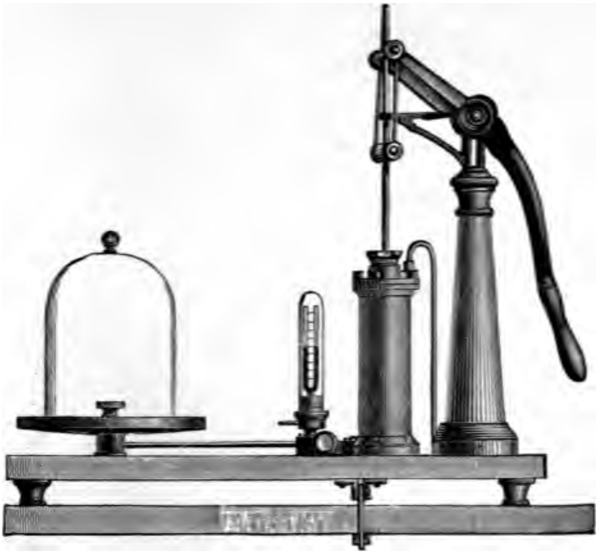

FIG. 78.—THE AIR-PUMP.

around it. When the piston is raised, it lifts the rod high enough to open S′, but cannot lift it farther, because of the button at the top of

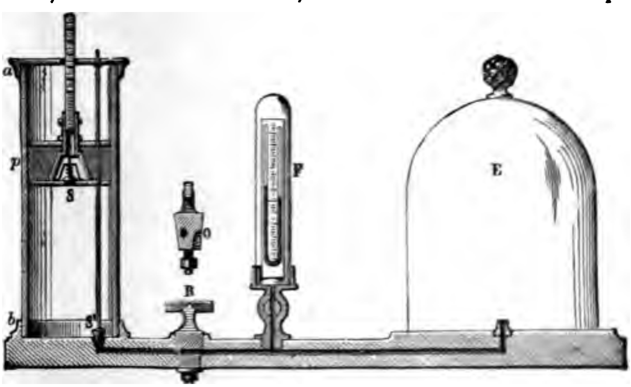

FIG. 79.—THE INSIDE OF AN AIR-PUMP.

the rod. Since the action of the valve S′ does not depend upon the

tension of the air in the receiver, this pump will produce a more nearly perfect vacuum ; but it is evident that this could not produce an absolute vacuum, and the impossibility of making perfect machinery renders the vacuum appreciably less perfect than in theory it ought to be.

Air-pumps are often made with *two* barrels, in order to exhaust the air more rapidly; and many different forms of the machine have been devised for the same purpose.

185. **The Air-Pump Gauge.**—In Fig. 79, F is a gauge to show how much of the air is exhausted. It is a U-shaped tube, closed at one end, containing mercury, and enclosed in an air-tight glass case, into which there is an opening from the receiver. Before the pump begins to work, the mercury is all standing in the closed end of the tube, which it fills to the top, and is kept there, of course, by the pressure of air down the open end, which is the same then as the pressure of the air outside. When part of the air has

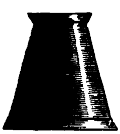

FIG. 80.—HAND-GLASS.

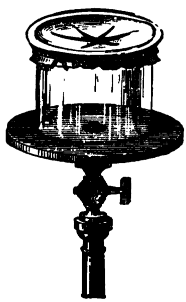

FIG. 81.—THE BURST BLADDER.

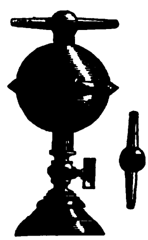

FIG. 82.—MAGDEBURG HEMISPHERES.

been exhausted, the tension of the air in the pump is not great enough to hold up the mercury in the closed tube, and it gradually falls. If a perfect vacuum were made, the mercury would, of course, stand at the same height in both tubes. The branches of the tube are usually only a few inches long, as the gauge is not needed until most of the air is exhausted.

Another form of gauge is sometimes made by attaching

a long glass tube to the air-pump by a rubber tube, and then putting the lower end of the glass tube in a vessel of mercury. As the air is exhausted, the mercury will rise in the tube.

How high would it rise if the pump could produce a perfect vacuum?

186. **Experiments with the Air-Pump.**—**Experiment 42.**—Take a *hand-glass* (Fig. 80), and set it upon the brass plate of the air-pump, in the place of the receiver.[1] Cover the top of the glass closely with one hand, and work the pump. As the air below is exhausted, the pressure of the air above is felt, and presently it becomes difficult to remove the hand from the top of the hand-glass.

Experiment 43.—Tie a piece of wet bladder tightly around the top

FIG. 83.—THE WEIGHT-LIFTER.

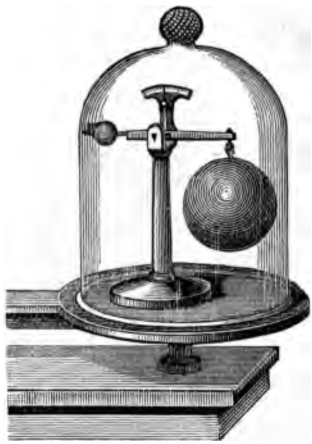

FIG. 84.—WEIGHT IN A VACUUM.

of the hand-glass, or around the top of a bladder-glass; after drying it thoroughly, put it upon the air-pump, and exhaust the air, the bladder will burst with a loud report: which way, inward or outward?

Experiment 44.—The Magdeburg hemispheres are two hollow brass hemispheres, which will fit very closely together. After cleaning and greasing the edges, put the hemispheres together, and screw fast to the air-pump. After exhausting the air, turn the stop-cock,

[1] Here, as in all experiments with the air-pump, unless the lower edge of the glass vessel is carefully ground, it must be coated with tallow, to keep air from passing between it and the brass plate. The edge of the glass and the brass plate should be cleaned beforehand.

remove from the air-pump, and screw on the second handle. Two students will find that they may pull hard, yet not pull the two hemispheres apart. Turn the stop-cock, and they fall apart:[1] why?

Experiment 45.—Put a foot-ball *partly* filled with air, or a partly-blown bladder, under the receiver of an air-pump. Exhaust the air, and the foot-ball or bladder will swell out: why? Try the experiment with raisins or a shrivelled apple under the receiver.

FIG. 85.—FOUNTAIN IN A VACUUM.

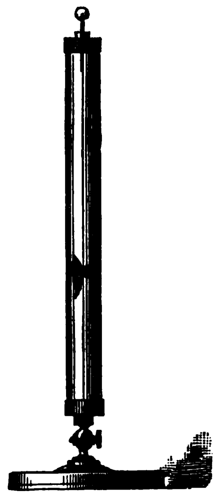

FIG. 86.—FEATHER AND COIN.

Experiment 46.—"Bursting bombs," air-tight cubes, or flasks of thin glass may be bought from any dealer in philosophical apparatus. Put one under the receiver, and exhaust the air. It will burst with considerable force. Explain.

Experiment 47.—Attach the top of the *weight-lifter* (Fig. 83) to the air-pump by a rubber tube. Exhaust the air, and the weight will be drawn up: why?

Experiment 48.—Carefully balance a good-sized light metal ball, then put it under the receiver, and exhaust the air. The ball will now be found to be heavier than the weight: why? (See Art. 181.) For this experiment a hollow metal ball is commonly used. Should there be an opening into the ball? Any light solid or liquid, such as a glass

[1] The Magdeburg hemispheres were invented by Otto von Guericke, the inventor of the air-pump. The hemispheres get their name from the city in Germany where the inventor lived. He made a very large pair, and in an exhibition before the Emperor of Germany it is said that several horses were unable to pull them apart.

bottle (should it be stoppered?), may be thus weighed outside and then inside the vacuum. Why ought the body weighed to be lighter (less specific gravity) than the weights used? Suppose it were the *same* as the weights? Suppose it were *heavier?*

Experiment 49.—Unscrew the top of the vacuum fountain apparatus (Fig. 85), screw it to the air-pump, and exhaust the air. Turn the stop-cock crosswise, and screw it into its base again. The pan at the bottom is filled with water, into which a tube, running up the stem, opens. If the stop-cock be turned, the water will rush up into the glass vessel in a fountain: why?

Experiment 50.—Fig. 86 shows a long, air-tight glass tube containing a feather and a small coin. Turn the tube upside down, and the coin will fall quickly to the other end, but the feather will lag slowly behind. Exhaust the air from the tube, and try the same thing. They will fall together: why? (Art. 181.)

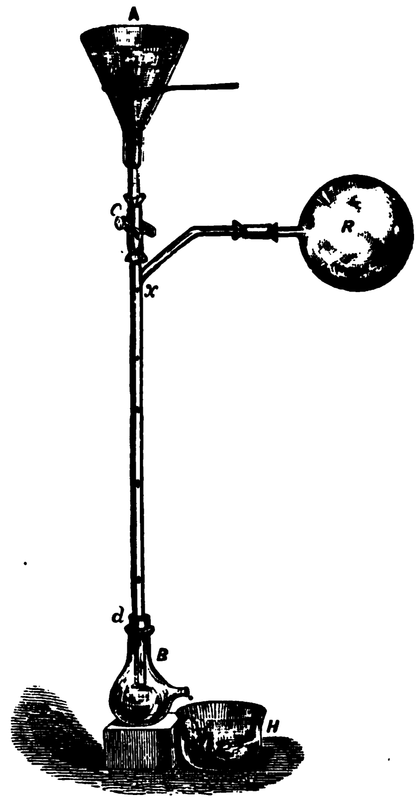

FIG. 87.—SPRENGEL'S AIR-PUMP.

187. Sprengel's Air-Pump.—The imperfections of the common air-pump have already been mentioned. A *very* good one will leave $\frac{1}{1500}$ of the air in the receiver. But Fig. 87 represents a much more perfect kind of air-pump. The funnel A contains mercury. The long, narrow glass tube *cd* opens into the funnel and dips at the lower end into the mercury in the bottle B. The receiver R, from which the air is to be exhausted, has air-

tight connections with the tube. The mercury running down the tube from the funnel separates into drops, *because its velocity increases as it falls.* Each drop is an air-tight piston, and between the drops are nearly perfect vacuums. As one of these vacuums comes to x, part of the air in R rushes out to fill it, and that air is carried down into the bottle B, where it comes to the surface as a bubble and disappears. In this way the air is drawn from R until almost a perfect vacuum is formed there. Under favorable circumstances, this pump leaves only $\frac{1}{1,000,000}$ of the air in the receiver.

As the exhaustion goes on, the mercury stands higher and higher in the tube, and finally is about 30 inches above the spout B. (Why?) With no intervening air-spaces, the opening x must therefore be more than 30 inches above the spout B. The whole apparatus is commonly about 6 feet high, and the upright tube is about $\frac{1}{10}$ of an inch in diameter. The process is slow, especially if the receiver be large. It is only by this pump that the necessary vacuum can be produced in the electric lamp of the present day.

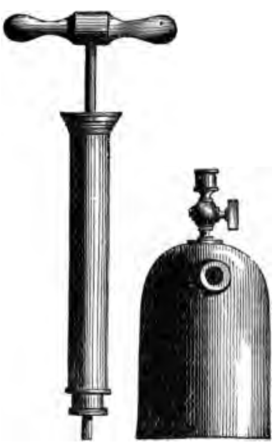

FIG. 88.—THE CONDENSER.

188. **Air-Condenser.**—If the two valves in the barrel of the air-pump (Fig. 79) were turned the other way,—that is, if both opened *downward* instead of upward,—it is clear that every stroke of the piston would drive air *into* the receiver. Such a piece of apparatus is called a condenser.

189. **Uses of Compressed Air.**—Compressed air is used for operating locomotives, drills, etc., in mines and tunnels, where a fire for steam would produce an accumulation of poisonous gas. But its most extensive application is in the air-brake.

190. The Automatic Air-Brake.—The essential parts of the air-brake are an air-pump (condenser) worked by steam, and a reservoir to contain compressed air, on the engine; an auxiliary reservoir for receiving compressed air, and a cylinder and piston, under each car. The air-pump keeps the main and auxiliary reservoirs charged with compressed air. A general idea of the brake under each car, also its automatic character, may be gained from Fig. 89. P is the main pipe from the engine. Compressed air from P is admitted to the intricate "triple valve" V. In this there are pistons and slide valves so arranged that when the pressure is "on," the air passes directly through to the auxiliary reservoir R. When the pressure in P is lowered, by the engineer or by the breaking of the hose coupling, the compressed air in R drives back a piston in V, and opens for itself a passage into the cylinder C, into which it rushes, driving the piston p to the left and pressing the brake-shoes against the wheels through a system of rods and levers attached at h. To release the brakes the engineer turns his valve so as to restore the pressure in P. The piston in V is thus driven to its original position, admitting the air to R, and at the same time uncovering a passage, e, through which the air in the cylinder C escapes to the atmosphere. The spring in C then forces back the piston, and the brakes are off.

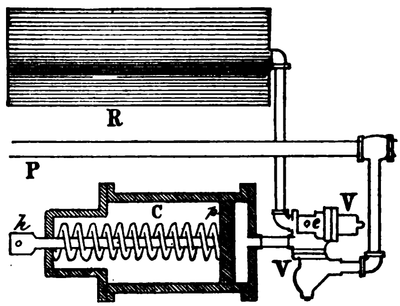

FIG. 89.—AUTOMATIC AIR-BRAKE.

191. The Common Pump.—Fig. 91 shows the common pump. It consists of a tube (pump-stock), in which works a piston having in it a valve opening *upward*. Opening into the bottom of this there is a narrower tube, which runs down into the water. At the top of this tube is another valve, also opening upward. To show how it works, suppose that no water is standing in the pump. When the piston moves up from the bottom of the pump-stock, as *its* valve *remains* closed, it tends to form a vacuum

below it. The atmospheric pressure upon the surface of the water in the well drives up water, and the air in the tube above it, to fill this vacuum. When the piston descends, the lower valve falls, and keeps there the air and water that have been drawn up from below, and the valve in the piston opens to allow the piston to pass through this air and water in the pump-stock. The next stroke of the piston raises the air and water above it to the spout, and the water rises from the well as before to fill its place. And at each successive stroke the pump-stock full of water is pumped out.

If the valves are tight, the tube and pump-stock are usually standing full of water, so that the latter begins to flow at the first upward stroke.

192. **Depth from which Water may be raised by the Common Pump.**—We have found that the atmosphere will sustain a column of mercury 30 inches high; and, as mercury is about 13½ times as heavy as water, the atmosphere will sustain a column of water 13½ times 30 inches high, or about 34 feet. Since the atmospheric pressure will raise water 34 feet, if a pump were perfectly made it would work as long as the *upper* valve was within that distance from the bottom of the well. Practically, however, the upper valve ought never (*i.e.*, at the upper end of the stroke) to be more than about 25 or 26 feet from the surface of the water.[1] Water can be raised farther than that by having the upper part of the pump-stock lengthened so

[1] It was through the observation of this fact that Galileo (gal-i-lee′o) (great Italian astronomer and philosopher, 1564–1642) first suggested the true cause of water rising in a pump. It had formerly been explained by saying that nature abhorred a vacuum and therefore the water rose to fill the vacuum caused by the piston. The Grand Duke of Tuscany wished to pump water from a depth of 40 or 50 feet, but the pumps would not work. Galileo found that the water would rise but 32 feet, and suggested that it was the weight of the atmosphere that supported the water at that height. His pupil Torricelli (1608–1647) afterwards discovered that the atmosphere would support 30 *inches of mercury*, as explained in Art. 170.

as to bring the spout some distance above the upper end of the stroke of the piston. The piston then *lifts* the water above it to the spout.

Fig. 90.—A Force-Pump.

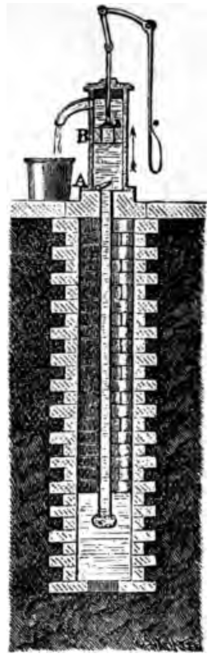

Fig. 91.—The Common Pump.

193. The Force-Pump.—To raise water higher than 26 feet, force-pumps are often used. Fig. 90 represents a simple kind. The piston is solid. The up-stroke draws the water from the well and fills the pump-stock with it. The down-stroke closes the lower valve and forces the water through the side-valve and up the pipe seen there.

194. Force-Pump with Air-Chamber.—Sometimes force-pumps are furnished with air-chambers to cause a continual flow of water. Fig. 92 shows a model of such a pump. The water is forced up into the tube which branches off to the left, and compresses the air there into the upper

part. This presses upon the surface of the water and drives it in a constant stream through the small tube.

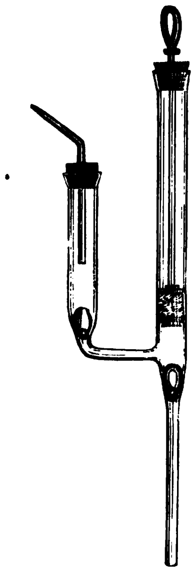

FIG. 92.—FORCE-PUMP.

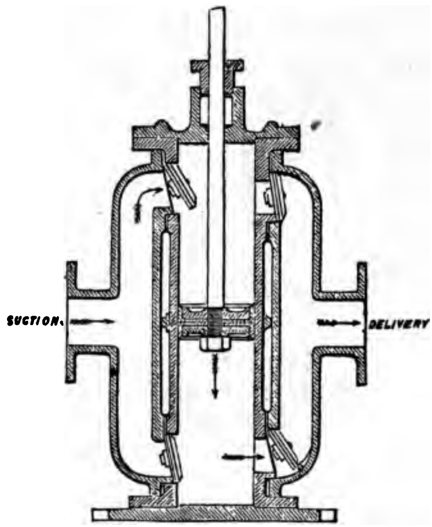

FIG. 93.—DOUBLE-ACTING FORCE-PUMP.

If the water is to be driven to a considerable height, much more work is required for the down-stroke than for the up-stroke. This difference is obviated by using the

195. **Double-Acting Force-Pump.**—This pump has both inlet and outlet valves at each end. There are many forms, but the principle of all is shown in Fig. 93. The piston in this class of pumps generally moves horizontally. The delivery-pipe is furnished with an air-dome, as shown in the hydraulic ram.

The steam fire-engine is generally a powerful double-acting force-pump, though many effective appliances are used. The pumps used to drive water into steam-boilers are, of course, force-pumps, though a device known as an *injector* frequently takes the place of the pump.

196. **Rotary and Centrifugal Pumps.**—For emptying quarries, coffer-dams, and other uses where large amounts of water are to be raised short distances, various forms of rotary and other paddle-wheel pumps are used, which employ rapidly-revolving wheels in circular boxes rather than pistons in cylinders.

197. **The Siphon.**—If a tube open at both ends be bent, as in Fig. 94, having one arm longer than the other, we have a *siphon*. If this be filled with water, and then be placed, as in the figure, with *the short arm* in a vessel of

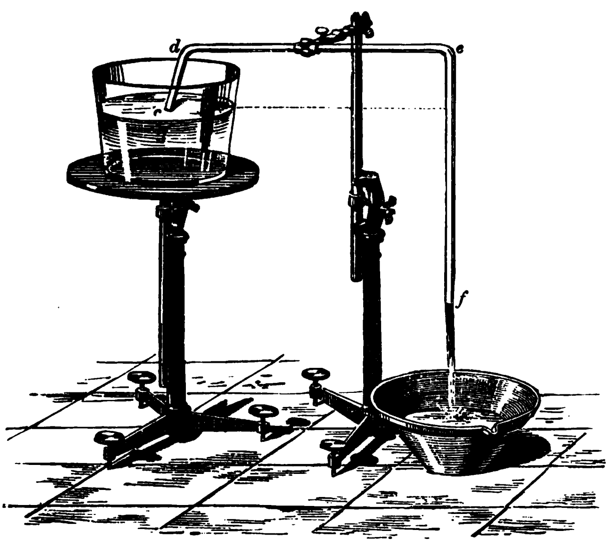

FIG. 94.—A SIPHON.

water, the water in the tube will, of course, tend through gravity to flow down, and out of, both arms of the tube; but this it cannot do, because it would leave a vacuum above. And as the long column, *ef*, is heavier than the short one, *dc*, the water runs *down* the long arm, and that in the vessel flows *up* the short arm (through the pressure

of the air upon the water in the vessel) to fill the vacuum there, and in this way the vessel may be emptied of the water.

198. **Starting the Siphon.**—It is evident that the siphon will not start itself. It may be filled by putting it under water, and then both ends must be closed by the fingers

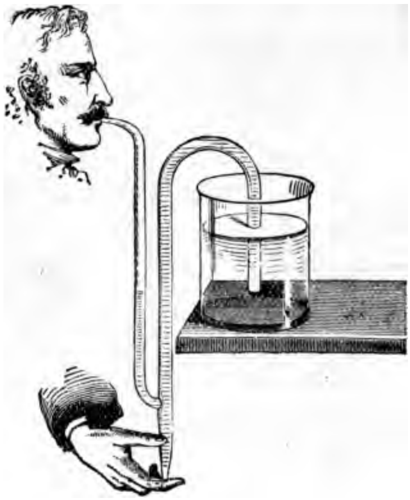

FIG. 95.—A SIPHON WITH EXHAUST-TUBE.

until it is in position. Or it may be put in position empty and filled by sucking at the end of the long arm. Where this cannot be done, or is undesirable, the siphon can have a suction-branch, as in Fig. 95.

Why is the end of the siphon kept closed by the finger in starting it? Will it be necessary to suck the long arm *full* before the siphon will begin to run?

199. **Uses and Limitations of the Siphon.**—The siphon is often used to empty vessels of liquids. It may be used to carry the water from a spring over a low hill to a house or a barn which is below the level of the spring.

The end of the tube from which the liquid flows must always be *below the surface* of the liquid in the vessel. If the surface should

be lowered until it is on the same level with the outlet, the flow will stop. As atmospheric pressure will not raise water more than

FIG. 96.

FIG. 97.—TANTALUS'S CUP.

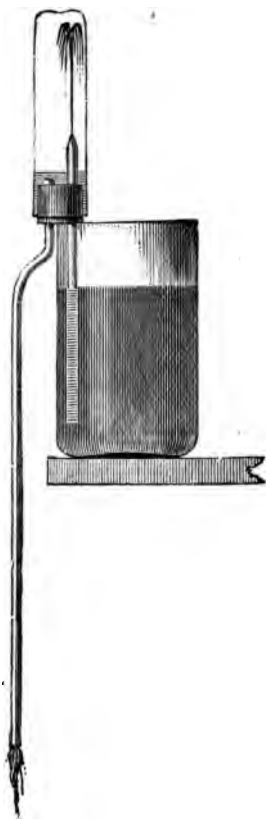

FIG. 98.—SELF-ACTING FOUNTAIN

34 feet, if water is to be siphoned, the top of the curve must not be more than 34 feet higher than the surface of the water.

200. **Experiments with the Siphon.** —**Experiment 51.**—Fig. 96 represents a vessel with a closely-fitting lid which has two openings in it. Through a cork fitting one of these openings runs a siphon-tube. After being started, the water in the vessel will flow, but will stop when the other opening in the lid is stopped by the finger: why?

Experiment 52.—Fig. 97 represents the "cup of Tantalus." It will be noticed that the handle is a siphon, the short arm of which opens into the bottom of the cup. When the cup is filled full, or when it is tilted so as to bring the water up to the highest part of the handle, the water will begin to run, and will empty the cup.

Fig. 98 shows how a self-acting fountain can be made of the bottom of a glass bottle, a cork, and two glass tubes. A dandelion-stem will make a good siphon. Try it.

201. **Intermittent Springs.**—These are springs which flow only at intervals. They have been explained on the principle of the siphon. Fig. 99 shows how this may be. If a reservoir in the earth had such a siphon-shaped outlet as is there shown, when it filled up to the bend of the outlet,

the water would run until the reservoir was emptied, and then would cease running until filled up to the bend again.

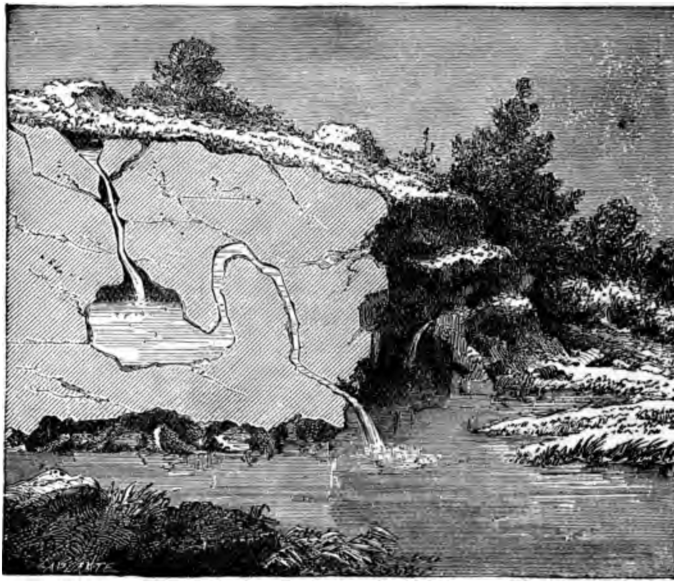

FIG. 99.—THE INTERMITTENT SPRING.

Exercises.—1. In Fig. 71 the mercury stands 90 inches higher in the long tube than in the short one. If *ab* equals 6 inches, how many inches of air are there below *b*? *Ans.* $1\frac{1}{2}$ inches.

2. How many inches of mercury have been poured in to condense this? *Ans.* 99 inches.

3. If one column is 20 inches higher than the other, what is the length of the air-column in the short arm? Since the pressure is $1\frac{2}{3}$, or $\frac{5}{3}$ as great as before, the air will occupy $\frac{3}{5}$ as much space, or $3\frac{3}{5}$ inches.

4. If one column is 10 inches higher than the other, what is the length of the air-column in the short arm? *Ans.* $4\frac{1}{2}$ inches. What if it is 45 inches higher?

5. The specific gravity of mercury is 13.6, that of alcohol is .8: how high a column of alcohol will the atmosphere support? *Ans.* 42 feet 6 inches.

6. How high a column of sulphuric acid, whose specific gravity is 1.8, will the atmosphere support?

7. A tumbler whose sides are vertical is inverted and pushed down into water until the air is condensed into the upper half of the

tumbler: how deep is the tumbler? *Ans.* 34 feet. Is it the bottom, the middle, or the top of the tumbler that is 34 feet deep?

8. How deep must the tumbler be if the air is compressed into the upper third of it? *Ans.* 68 feet. How deep if it is compressed into the upper fifth of the tumbler?

9. How high will the barometer stand at a place 1800 feet above the sea?

10. What part of the air is left in the receiver of an air-pump when the mercury in the gauge is 3 inches higher on one side than on the other? *Ans.* $\frac{1}{10}$. When $\frac{1}{2}$ inch higher?

11. What is the difference of heights in the gauge when $\frac{1}{1500}$ of the air is left in the receiver?

12. A pair of Magdeburg hemispheres have a diameter of 3 inches. If the air were perfectly exhausted, what force would it take to pull them apart? *Ans.* 106 pounds.

13. Otto Guericke's hemispheres are said to have been 2 feet in diameter. Had he been able to exhaust all the air, what force would have been needed to pull them apart? It is sometimes said that 30 horses, 15 on each side, were unable to pull them apart. Can that be true?

14. If the inside diameter of a weight-lifter is 6 inches, what weight will it lift, provided a perfect vacuum be produced?

15. Bunsen's air-pump uses falling water as Sprengel's does falling mercury: how long must the tube below x be?

16. Denver, Col., is about 1 mile above sea-level: how high would a perfect pump raise water there? *Ans.* 28 feet. (See foot-note, p. 94.)

17. If a certain pump will raise fresh water 25 feet, how high will it raise salt water?

SUMMARY OF CHAPTER IV.

The characteristic of gases is the repellent action of the molecules on one another.

The volume of a gas varies inversely as the pressure per unit area which it sustains.

The pressure of the atmosphere at the level of the sea is nearly 15 pounds on every square inch of the earth's surface.

This pressure decreases as we ascend, but the decrease in pressure for the same increase in altitude is less the higher we go.

The upper limit of the atmosphere is undetermined, but it is where the repellent force of the molecules (weak in a rarefied gas) is exactly balanced by gravity.

Air-pressure is measured with the barometer, the whole atmosphere at sea-level being able to hold the mercury about 30 inches high, equivalent to a column of water nearly 34 feet high.

Air transmits pressure perfectly, and compressed air is perfectly elastic, rendering it available as a working agent.

CHAPTER V.

SOUND.

SECTION I.—THE CAUSE AND PHENOMENA OF SOUND.

202. **Sound is a Vibration.**—All sound is caused by the vibration of some body. When a violin-string is sounded, the vibrations can be seen. If a tuning-fork be sounded, and the fork be touched to the lips or teeth, the vibrations can be felt.

Experiment 53.—Fasten, with wax, a short bit of fine wire, or a bristle, to the end of one prong of a tuning-fork. Sound it by striking it against the table, and draw the end of the wire gently over a piece of smoked glass. The vibrations of the fork will trace a beautiful wavy line on the glass.

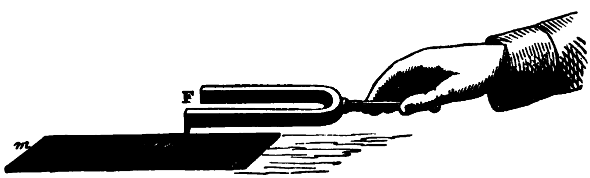

FIG. 100.—TUNING-FORK RECORDING ITS VIBRATIONS.

The word sound is used in two senses. It is sometimes used to denote *the vibration of the sounding body*, but is oftener used to denote *the effect of this vibration upon an organ of hearing.* Accordingly, when the old question, "If a tree were to fall in a forest fifty miles from any living being, would there be any sound?" is asked, the answer depends upon which definition of sound is taken.

203. **Sound usually brought to the Ear by Vibrations of the Air.**—As sound is always caused by the vibrations of some body at a distance from the ear, there must be some *way by* which it is carried to the ear. This is almost

always done by vibrations of the air, as may be shown by the following experiment.

Experiment 54. — Set a small clock, or a music-box, under the receiver of an air-pump, taking care to put under the clock a number of thicknesses of flannel. Exhaust the air, and the ticking of the clock, or the sound of the music-box, will grow fainter and fainter, until it can no longer be heard.

Fig. 101 shows a bell which can be kept ringing by clock-work, and is hung by cords in the receiver of an air-pump, which is often used to prove this fact. Here, as also above, the experiment is more satisfactory if, after the air is exhausted as far as possible, the receiver be filled with hydrogen and again pumped out. Fig. 102 is a simpler piece of apparatus to illustrate the same thing.

On the tops of high mountains sounds are considerably fainter than upon the surface of the earth: why?

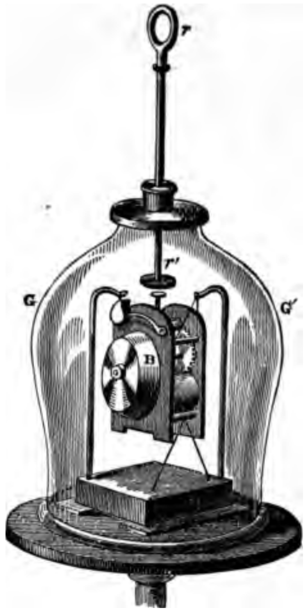

FIG. 101.—BELL IN A VACUUM.

204. How Air conveys Sound.—Suppose a tuning-fork be sounded and held at one end of a tube, as shown in Fig. 103. As the prong of the fork flies out, it will drive the air that is in front of it forward a little way and compress it. This air will condense and drive forward the air in front of it, and so the condensation will be driven through the tube. *Any one particle of air moves forward only a very little way, when it gives its motion to the particle ahead of it, but the condensation, or the wave, moves through the whole tube.* Sound-waves are just like water-waves, as described in Art. 159, except that in sound-waves the particles of air move

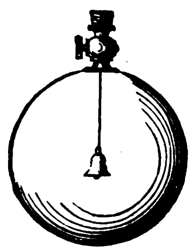
FIG. 102.—BELL IN A VACUUM.

lengthwise, but in water-waves the particles of water move up and down.

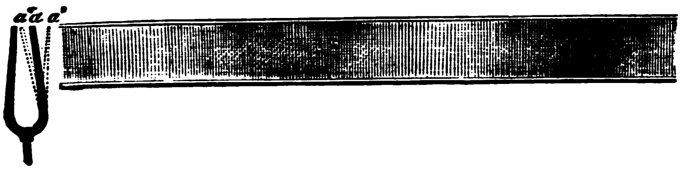

FIG. 103.—SOUND-WAVES IN A TUBE.

The sound-wave is not a puff or blast of air, such as you blow from your mouth. Tyndall[1] has shown this very neatly by the following experiment.

Experiment 55.—Fill the long tube shown in the figure with smoke from burning paper, set a lighted candle at one end, and make a loud noise, by clapping two blocks together, or otherwise, at the other end. The flame will be put out, yet no blast of air rushes through the tube, for the smoke has not been driven out.

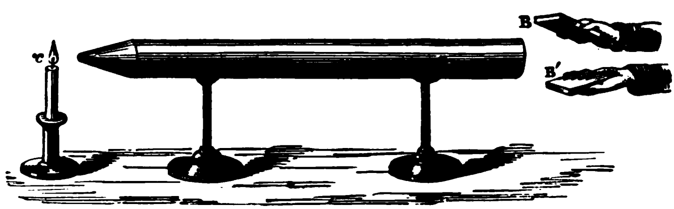

FIG. 104.

In the open air these condensations move in all directions. Each one must therefore be a spherical shell, growing larger as it moves farther in every direction from where the sound was made. Following every condensation there must of course be a rarefaction. And so these successive waves of condensation and rarefaction are constantly given out in all directions as long as the sounding body vibrates.

[1] John Tyndall (1820–1893), an English natural philosopher, and one of the greatest of scientists. "Tyndall on Sound" is the best book on this subject in the English language for most readers and students.

205. Velocity of Sound in the Air.—Every one who uses this book has probably noticed that when a whistle, some distance off, is blown, the escaping steam can be *seen* a little time before the sound can be *heard*, and that the sound keeps coming just as long after the steam can be seen to have stopped. And when a wood-chopper is working at a considerable distance, you hear the blow after you see it. As we shall presently learn, light travels so exceedingly fast that we *see* the steam immediately after it escapes, so that the difference between the times of seeing it and hearing the whistle is the time that it has taken the sound to travel from the whistle to us.

The velocity of sound through the air has been very carefully measured. It is found to vary according to the temperature. When the temperature of air is at the freezing-point of water, 32 degrees in our common thermometers (Fahrenheit's), sound travels through it 1090 feet per second. And its speed is about 1 foot more per second for every degree that the thermometer is above 32°.

How fast does sound travel through the air when the temperature is 70°?

206. Solids and Liquids may also convey Sound.

Experiment 56.—Get a companion to scratch one end of a long piece of wood (a board in the floor or a sound fence-rail will do) lightly with a pin. By putting your ear to the other end you can hear the scratch distinctly, although you cannot hear it through the air when you lift your ear from the wood. Try the same thing with a long bar of iron.

Experiment 57.—Get a companion to strike two stones together 10 feet from you, and notice how loud it sounds. Hold your head, or one ear, under water while he strikes the stones together under the water, at the same distance, and notice how much louder it sounds.

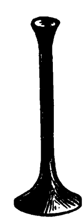

FIG. 105.—STETHOSCOPE.

Sound travels faster and farther through solids and liquids than through the air. Through iron it travels about 16,000 feet per second, through most kinds of wood almost as fast, and through water about 5000 feet per second. The *stethoscope* is a small tube of wood or metal widening out at one end, which is much used by physicians. The physician places the wide end upon

his patient's chest, and puts his ear to the other end. The faint sounds made by the organs in the chest are distinctly carried to his ear through the stethoscope, and he can judge of their condition. The Indians are said to put their ears to the ground and thus hear the approach of their enemies long before it could be heard through the air.

The ordinary *string telephone* which boys make by knocking the bottoms out of two fruit-cans, stretching parchment tightly over one end of each, and joining these parchments with a stretched string, will convey sound quite a distance. A whisper in one can easily be heard in the other across the street. And when carefully made and very fine copper wire is used instead of string, conversation can be carried on through them for a quarter of a mile or farther.

Experiment 58.—Suspend a poker by two strings, and thrust the fingers holding the poker into your ears. Then swing the poker against a piece of wood, and you will be surprised at the sound.

207. **Loudness of Sound.**—Tap a table gently, and a faint sound is produced; strike it hard, and a loud sound is produced; or, better, pull a violin-string a very little to one side, and it sounds faintly; pull it strongly to one side, and it sounds loud. *Short vibrations of the sounding body produce faint sounds, long vibrations produce loud ones.* Short vibrations of the sounding body make short vibrations of the particles of air, and longer vibrations of the body make longer vibrations of the particles of air. Hence although each particle of air in a sound-wave moves only a very short distance forward and backward, yet it makes a longer swing when conveying a *loud* sound than when conveying a *faint* one.

208. **Loudness of Sound affected by Distance.**—Common experience teaches us that all sounds grow fainter as they get farther from the sounding body, and finally become too faint to be heard. But if, instead of being allowed to spread in every direction, the sound be confined to a narrow tube, it is carried much farther. Hence *speaking-tubes* are often found in large buildings so arranged that a whisper into one end of the tube can be heard at the other end in the farthest corner of the building. *Speaking-trumpets* are much used at sea to enable the voice of the officer in command

to be heard better and farther in any one direction. They seem to guide the sound of the voice in one direction, so

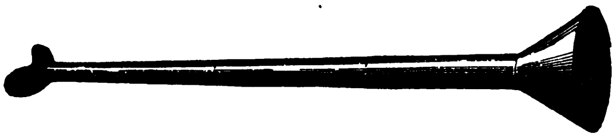

FIG. 106.—SPEAKING-TRUMPET.

that it is louder and goes farther than if allowed to spread. *Ear-trumpets* are funnel-shaped instruments that collect all the sound that enters the mouth of the funnel and concentrate it into a small opening at the other end of the ear-trumpet. By putting the small end to the ear, partially deaf persons can hear better.

FIG. 107.—EAR-TRUMPET.

If sound moves through the air unobstructed in all directions, and if the air is uniform, or homogeneous, *the loudness must vary inversely as the square of the distance from the sounding body.* Twice as far off the sound would be one-fourth as loud, three times as far off one-ninth as loud, etc. This is because at twice the distance from the sounding body the air in a hollow shell or surface of a sphere of *twice* the former radius is vibrating. But surfaces of spheres increase according to the *squares* of the radii; therefore the sound is spread out over *four* times as much surface, and must be one-fourth as loud at any one place.

209. **Conditions of the Atmosphere as affecting Sound.**—Although sound travels many times faster than the strongest wind, yet it can often be heard three or four times as far with the wind as against it. The cause is not certainly known.

It was formerly thought that rain, snow, fog, etc., obstructed sound; but Tyndall has recently shown that they have no effect whatever upon the transmission of sound. The same observer has shown the existence of *acoustic clouds* in the atmosphere. These are masses of air differing from the surrounding air in *temperature*, or in the amount of

moisture they contain. They have no connection with ordinary clouds, they are entirely invisible, and the air may be full of them upon the clearest day. Yet they obstruct and reflect sound very much. It is to the reflections from these acoustic clouds that the rolling of thunder seems to be mainly due. And probably the fact that noises are heard farther and more distinctly by night than by day is partly due to there being fewer acoustic clouds formed by night than by day, and partly also to the stillness of the night.[1]

210. **Reflection of Sound.**—When sound-waves strike a wall or other obstruction, they rebound or are reflected, and the angle of reflection is equal to the angle of incidence.

Fig. 108 illustrates an experiment in the reflection of sound. Two concave metal mirrors are placed facing each other and so far apart that the ticking of a watch could not be heard from one to the other. Then, as shown in the figure, a watch is hung in front of one so that the sound-vibrations are reflected out from the mirror in a straight line to the other one, which concentrates them so that if the ear is placed there, or if a short speaking-tube runs from there to the ear, the ticking of the watch can be distinctly heard.

211. **Whispering-Galleries.**—In some large circular buildings it is found that low whispers spoken near the wall on one side of the building can be heard distinctly at the opposite side. The sound seems to be reflected repeatedly until it reaches the opposite side, when it is so concentrated from all directions that it is distinctly heard. The gallery in the dome of St. Paul's Cathedral in London is a famous whispering-gallery. The dome in the Capitol at Washington is another.

212. **Echoes.**—When the reflecting surface is near the source of the sound, as the walls of an ordinary room in

[1] The writer's own observations leave no doubt in his mind that the popular notion that distant sounds can be heard more distinctly before a storm is correct. Probably at such a time the air is homogeneous and free from these acoustic clouds; but some instances are *not easily* explained in this way.

which a sound is made, the reflection follows the sound itself so closely that it cannot be distinguished from it. It

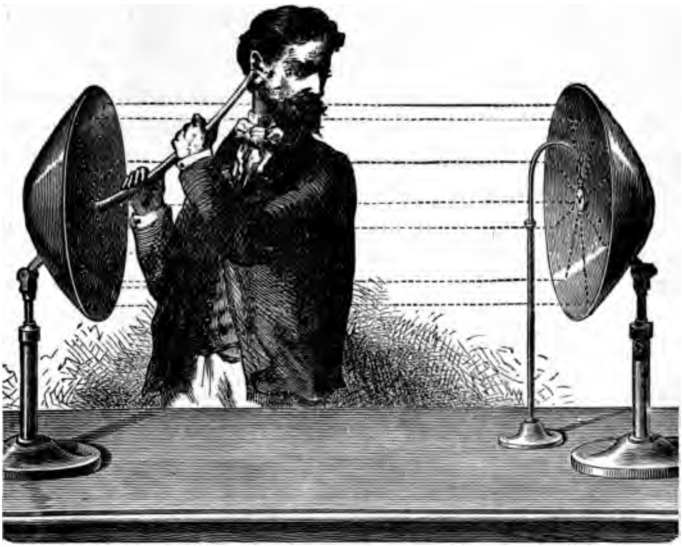

FIG. 108.—CONCENTRATION OF REFLECTED SOUND.

may, however, modify one's voice in some way and give a peculiar *resonance* to the room. But when the reflecting

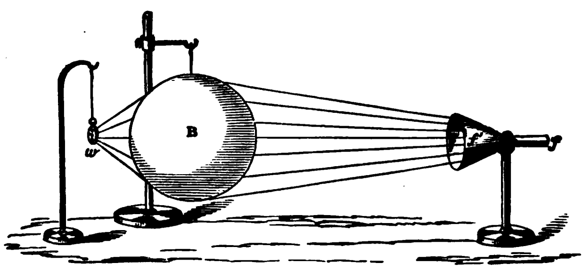

FIG. 109.—REFRACTION OF SOUND.

surface is fifty feet or more away, the reflection can be heard after the sound ceases, and is called an *echo*.

Between two walls, or between cliffs, and in like places, echoes are often repeated many times by being reflected from side to side. Large halls sometimes have an echo that is very annoying to both the speaker and his hearers. In such cases the echo is generally less when the hall is filled with people, and especially so if the seats rise towards the back of the hall, or if there is a gallery there.

213. **Refraction of Sound.**—Fig. 109 shows how a faint sound may be concentrated so as to be heard farther off than it could otherwise be heard. *B* is a small balloon filled with some gas *heavier* than air, as carbonic acid. The waves of sound are bent around, or refracted, by the heavy gas and concentrated at one point. If the ear is placed there, or if a funnel is placed there to convey the sound to the ear, the ticking of the watch may be distinctly heard. This refraction of sound is like the concentration of the sun's heat with a burning-glass. In light it is a very important subject, and will be fully taken up there.

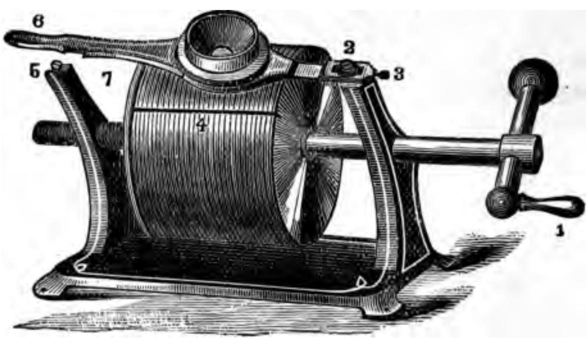

FIG. 110.—EDISON'S PHONOGRAPH.

214. **The Phonograph.**—Fig. 110 represents a *phonograph*, a remarkable talking-machine recently invented by Mr. Edison.[1] 4 is a brass cylinder into which is cut a continuous groove, winding around it from one end to the other. When the handle 1 is turned, the screw-thread, seen under 7, moves the cylinder slowly along to the left

[1] Thomas A. Edison (1847–), a famous American inventor, who *lives at* Menlo Park, New Jersey.

while it is revolving. Above 4 is the mouth-piece, the bottom of which is covered with a thin elastic metal plate. From the under side of this plate a short needle runs down. To use the phonograph. a piece of tin-foil is wrapped tightly around the brass cylinder, and the handle 6 is pushed down upon the screw-head 5 and held there. This presses the needle down upon the tin-foil. If the handle is turned as the cylinder revolves and moves to the left at the same time, the needle pushes the tin-foil down into the groove beneath it, and thus makes a shallow spiral groove in the tin-foil. But if you talk into the mouth-piece the sound-waves will make the elastic plate vibrate, and the needle, being attached to it, will also vibrate up and down, and will make successive dots and dashes in the bottom of the groove in the tin-foil. If we were to take the tin-foil off the cylinder and examine the bottom of the groove with a microscope, we should find a peculiar indentation for every pulse of the sound-wave. But, instead of taking the foil off the cylinder, let us raise 6 and run the cylinder back to the starting-place. If the needle be now pressed down into the groove and the handle be turned as it was when we were talking to it, the indentations there will cause the needle to vibrate up and down, precisely as it vibrated when it caused these indentations, and the needle will vibrate the plate, just as the plate at first vibrated the needle, and hence cause it to send out into the air the same vibrations or sounds as were driven against it when you talked to it. In this way the phonograph repeats the words said to it. as well as laughter, crying, and sounds of any kind. But, as its voice is feebler than yours, it needs for a speaking-trumpet a cone of paper, in order that it may be heard over a large room.

SECTION II.—MUSICAL SOUND.

215. **Noise and Musical Sound.**—When the sound-vibrations are irregular, no two at the same distance apart, we hear a *noise*, such as would be made by the crash of a pane of glass. But if the waves of sound follow one another at regular intervals, we hear a *musical sound*, such as is made by the prong of a tuning-fork or a violin-string, which vibrates regularly, and produces sound-waves all at the same distance apart. No matter how the vibrations are caused, if they are at regular intervals and rapid enough, they will produce a musical sound. Taps on a table, the striking of a stick upon the pales of a fence or the teeth of a wheel,

the puffs of a locomotive, if regular and rapid enough to blend together, produce a sound as truly musical as the voice of the best singer, or a note of a flute, though it may *not* be as pleasant.

If a number of boys should run across a room all keeping step, the noise of their steps would be heard at regular intervals; and if they could run so fast that the sounds from their steps would blend into one continuous sound, they would make a *musical note*. But if the same boys were to run back just as fast without keeping step, their steps would make a *noise*.

216. **Pitch of Sounds.**—**Experiment 59.**—Run the back of a knife over the milled edge[1] of a coin. You will produce a musical sound. Run the knife over the edge *faster*, and your sound will be higher; run it still faster, and the pitch will be still higher.

Experiment 60.—Wind a string around the axis of the wheel (Fig. 111), and pull it so as to revolve the wheel rapidly. Hold a card to the teeth, and a musical sound is produced. Revolve the wheel faster and faster, the pitch becomes higher and higher.

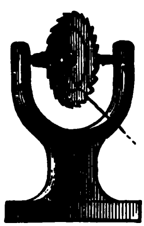

FIG. 111.

These experiments show that *the pitch of sounds depends upon the rapidity of the vibrations.* Their *loudness* depends, as has been said, upon the extent of the vibration of the sounding body, and, therefore, of the particles of air; their *character*, such as distinguishes the sound of a violin from that of a piano or a human voice, is due to other causes; but the *pitch* of sounds is due solely to the number of vibrations per second.

217. **The Siren.**—The number of vibrations which produce any given pitch of sound is best found by means of a piece of apparatus called a siren, which makes a musical sound by a succession of puffs of air following one another

[1] If you notice, you will see that all the gold and silver coins now made in the United States have their edges finely notched. They are said to be *milled*. Perhaps you can think or find out why they are so made.

very quickly. Fig. 113 shows a siren cut open, so that its mechanism may be understood. Air is forced up through the tube below from a pair of bellows (not shown in the figure) into the air-chamber seen open. Leading up from this is a small opening, and above is a wheel made to revolve, and having a circle of holes in it. When one of the holes in the wheel comes over the hole in the top of the air-chamber, the air forced in by the bellows can puff out;

FIG. 112.—THE SIREN.

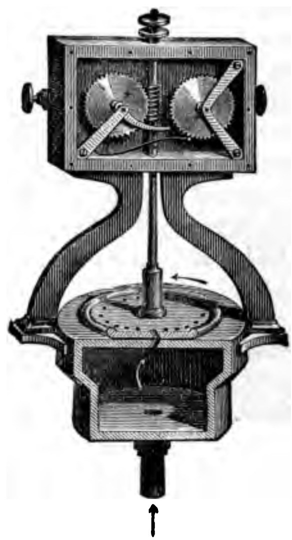

FIG. 113.—THE SIREN,—INSIDE VIEW.

when the solid part of the wheel is there, it cannot. So, as the wheel turns, a succession of puffs is heard as the holes in the wheel pass, one after another, over the hole leading up from the air-chamber. If the wheel turns fast enough, the separate puffs cannot be distinguished from one another, but are blended into one sound, rising higher in pitch as the wheel goes faster and therefore produces more puffs per second. By means of the cog-wheels seen at the top of the figure the wheel registers its revolutions, and the

hands on the dials (Fig. 112) show how many revolutions the wheel makes per second. This multiplied by the number of holes in the wheel gives the number of *puffs*, and therefore the number of sound-waves or vibrations, per second. It will be noticed in Fig. 113 that the opening[1] leading upward from the air-chamber slants. This forces the air obliquely against the wheel and causes it to revolve.

This ingenious little instrument will produce a note of any pitch, from the lowest to the highest, and tell us the number of vibrations it makes to produce it. And if a note be sounded on any musical instrument, the pitch of the siren may be raised (by working the bellows harder) until our ears tell us that its pitch is the same as that of the musical instrument; then the number of vibrations per second of the siren is the number that the instrument is making. In this way we can count the vibrations which the human voice, or any other musical sound of any pitch, is producing.

218. **The Limits of Human Hearing.**—It is found that when the puffs of the siren are fewer than 16 per second they are heard as separate puffs, but when they reach about that number they cannot be separately heard, and make a continuous and very low note. The lower limit of sounds, then, is about 16 vibrations per second, which make a sound of the lowest possible pitch. When the puffs reach about 38,000 per second their exceedingly shrill piercing note suddenly ceases, and though the wheel can be *seen* to be revolving, and, as the hands show, faster than ever, nothing can be heard. We have reached the *upper* limit of human hearing. The ear can hear nothing when the vibrations are more than about 38,000 per second.

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[1] There is really a *circle* of holes in the top of the air-chamber, corresponding exactly with the holes in the wheel, and when the air puffs through one hole it *puffs* through all. Only one puff is heard, but it is stronger, and the wheel can be driven around much faster, *than if there* were but one upward opening.

The pitch of the keys of our ordinary pianos ranges from 27 to 3482 vibrations[1] per second, while the middle C-string vibrates[1] 272 times per second. Human voices from the deepest bass of men to the highest treble of women lie between 80 and 1000 vibrations per second.

The upper limit of hearing varies in different persons, and very curious results often follow from this. "Nothing can be more surprising," says Sir John Herschel,[2] "than to see two persons, neither of them deaf, the one complaining of the penetrating shrillness of a sound, while the other maintains there is no sound at all." And Tyndall notes that in crossing the Alps with a friend, "the grass at each side of the path swarmed with insects, which to me rent the air with their shrill chirruping. My friend heard nothing of this, the insect-music lying beyond his limit of audition."

219. **Lengths of Sound-Waves.**—If the temperature of the air is 62°, sound travels through it about 1120 feet per second. And if a tuning-fork that vibrates 256 times per second is sounded, at the end of 1 second the first wave of sound must be 1120 feet from the fork, and the 256th has just left the fork, and so scattered through the 1120 feet there are 256 waves. As the tuning-fork gives out a *musical sound*, the waves must be at equal distances from one another, and, therefore, dividing 1120 feet by 256 gives us the distance between any two successive condensations, or the length of a wave. It is 4 feet 4½ inches.

When the temperature of the air is 82°, a man is speaking in a pitch that produces 120 vibrations per second: what is the length of one of the sound-waves? *Ans.* 9½ feet.

At the same temperature a woman's voice is producing 300 vibrations per second: what is the length of one of the sound-waves that she produces?

SECTION III.—MUSICAL INSTRUMENTS.

220. **The Sonometer.**—The piece of apparatus most commonly used in experimenting with musical sounds is the

[1] The vibrations meant here and elsewhere are from one side of the swing across to the other, and *back again*, sometimes called *double vibrations.*

[2] A famous English astronomer and scientist, born 1792, died 1871, son of the great astronomer Sir William Herschel.

sonometer. It is a long wooden box, over which one or more wires are stretched by weights. The wire rests on wooden bridges at the ends of the box, and between them is a bridge which can be moved anywhere along the scale

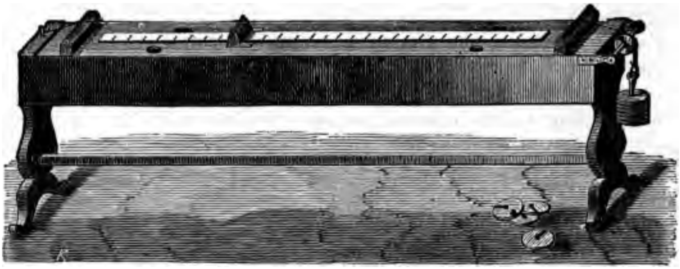

FIG. 114.—SONOMETER.

of inches which is marked off under the wire. If the stretched wire be pulled aside with the thumb and finger, or if it be bowed with a violin-bow, a clear musical sound will be produced that lasts a short time.

221. **The Laws of Vibrating Strings.** — If the wire be shortened, by moving the movable bridge, so that *half* of it vibrates, it is found to make *twice* as many vibrations per second as the whole wire. If *one-third* of it is vibrated, it will vibrate *three* times as fast as the whole; if *one-fourth*, *four* times as fast,[1] etc. Hence,

222. **The First Law.**—*The number of vibrations of a string is inversely proportional to its length.*

Without using the movable bridge, put more weights on the string until they are *four* times as heavy as at first, the string will vibrate *twice* as fast as at first; with *nine* times as much weight it will vibrate *three* times as fast, etc. Hence,

[1] The number of vibrations can be counted by bringing the siren to the same pitch and counting its vibrations; or any one even slightly acquainted with music can tell the relative number of vibrations by *the pitch*, as will be explained in the next section.

223. **The Second Law.**—*The number of vibrations of a string is directly proportional to the square root of its tension.*

If a second wire of the same material, but weighing *four* times as much to the yard, be stretched beside the first one, and the stretching-weights and the lengths are the same, it will vibrate *one-half* as fast; one *nine* times as heavy will vibrate *one-third* as fast, etc. Hence,

224. **The Third Law.**—*The number of vibrations of a string is inversely proportional to the square root of its weight.*

The Pitch of Vibrating Strings.—As the pitch of musical sound depends solely upon the number of vibrations per second, the laws of vibration are also the laws of pitch.

Experiment 61.—Vary the length of the wire, the stretching-weight, and the weight of the wire on the sonometer, and notice the changes in pitch.

Experiment 62.—Lift the lid of a piano, sound the highest key, and notice that the *shortest* wire[1] is struck. Strike the lowest key, the *longest* wire is struck: which law? Repeat the law to yourself. Notice also that the wires struck by the higher keys are very *thin* and *light*, while those struck by the lower keys are much *heavier* and have extra wire wrapped around them to make them heavier still: why? Repeat the law.

If you cannot play the violin yourself, watch some one tuning and playing one. Why are some of the strings heavier than others? Which have the highest pitch? What is peculiar about the one that has the lowest pitch?

What effect does it have upon the pitch to tighten up the strings in tuning the instrument? Repeat the law.

Why does the player touch the strings in different places while playing? Explain this fully by referring to the law.

225. **Sympathetic Vibrations.**—**Experiment 64.**—Sound a tuning-fork, and set the end of the handle on a table or against the panel of a door. It sounds very much louder than in the air. The vibrations of the fork have set the wood to vibrating too, and it sounds out louder than the fork.

The vibrations of the wood thus caused are called *sympathetic vibrations.* They are very commonly produced, and are of great importance in music and sounds generally.

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[1] In most pianos there are two wires for each key, both, of course, of the same length. In some of the better modern pianos there are three for each key.

For experimentation, tuning-forks are very frequently mounted upon sounding-boxes (Fig. 115), which strengthen the sound as the table did. It is not necessary that the sounding body actually touch another to set it to vibrating. It may be done by the sound-waves in the air.

FIG. 115.—TUNING-FORK ON SOUNDING-BOX.

Experiment 64.—Raise the lid of a piano, lift the dampers from the wires by putting your foot on the right pedal, and make a sound over the strings with the voice. The sound-waves set in motion by your voice cause the sounding parts of the piano to vibrate, and when your voice stops you hear the piano sounding *in exactly the same pitch as your voice had.*

Experiment 65.—If two tuning-forks *of the same pitch*, mounted on sounding-boxes, be placed side by side, and one of them be sounded, the other will take up the sound, and may be heard after the first is silenced. But if the pitch of one of them be lowered by sticking a small lump of wax upon one of its prongs, the sounding of the other will not set this one to vibrating.

The strings of a violin would give out very feeble sounds if they were not reinforced by the sympathetic vibrations of the wooden shell below them. Underneath the strings of a piano you may see a thin board,—the sounding-board. Without that the sound of the piano would be insignificant.

Experiment 66.—Touch the handle of a vibrating tuning-fork to the body of a violin or to the sounding-board of a piano, and notice how it sounds out. It will keep on sounding after you have taken away and silenced your fork. Do not fail to notice that it gives out the same pitch as the fork.

Experiment 67.—Stretch your sonometer wire, or one like it, across an open door-way, and notice the comparative feebleness of the sound. You see why you have a wooden box under your wire.

Professor Tyndall illustrated this, as well as the conduction of sound by solids, very beautifully in his lectures in London. On the second floor below his lecture-room he placed a piano. A pine rod rested on the sounding-board of the piano and came up through the floors in front of his desk. When the piano was played, the rod was *of course set in* vibration, but too feebly to be heard. When, how-

ever, Professor Tyndall laid a violin on the end of the rod, the vibrations of the rod set the wood of the violin to vibrating, and it reproduced the music of the piano so that it could be heard all over the room. A guitar, a harp, and even a thin flat board, when put in the place of the violin, reproduced every note of the piano.

226. **Resonance.**—This capability of being set to vibrating by sound-waves and of giving forth sound of the same pitch is called *resonance.* Different bodies possess it in various degrees according to their material and their shape.

Experiment 68.—Sound the tuning-fork and touch the end of the handle against your slate; a window-pane; a book, open and shut; a stone or brick wall; a lath-and-plaster partition; iron; stone; the blackboard-pointer; your hand, etc. Notice the differences in intensity, and whether they are due to the material or the shape of the body.

Resonance may also be caused by sympathetic vibrations of a body of air, and it is to such vibrations that the term is usually applied.

Experiment 69.—Fix the mouth as if about to say *e*, and bring a sounding tuning-fork close before it. Quickly change the mouth as if to say *o*, and notice that the sound is strengthened. The latter shape gave a more resonant body of air, hence the stronger sound.

Experiment 70.—(Fig. 116.) Take a deep glass jar and hold the sounding tuning-fork over its mouth. The sound of the fork will probably be only slightly strengthened. Pour water into the jar quietly; the resonance increases as the air-column shortens, until presently it becomes very strong. We have found the length of air-column which is best vibrated by the waves from our fork. If more water be poured in, the resonance decreases again.

Let us see if we cannot learn why one particular length of the air-column makes the resonance greatest. Fig. 117 represents the fork vibrating over the jar. As the prong moves from its position of rest down to *b*, the air is condensed below it, and the condensation moves down to the bottom of the jar (or to the surface of the water) and is reflected back again. In order that the vibrations of the air should fit those of the fork, the column of air ought to be long enough to allow this condensation (after reflection) to reach the prong again just as the prong reaches the middle of the vibration; or while the prong is making an excursion to one side and back to the middle again, which is half a vibration, the condensation must travel twice the length of the air-column. In swinging up from its middle position the prong produces a *rarefaction*, which must also travel to the bottom of the column and back again while the prong is making the

upper half of its vibration. It is clear that if the vibrations of the air-column did not thus fit those of the fork, they would interfere with one another or with the fork, and thus be weakened. When the vibrations of two bodies fit together, as do those of the fork and the column of air when the resonance is greatest, they are said to be *synchronous*.[1] Since a pulse must pass along the air-column *four times* during one complete vibration of the fork, the tube ought to be one-fourth the length of a sound-wave of that pitch. If the depth of the air-column which sounds loudest for a fork vibrating 256 times per second be measured, it will be found to be about 13 inches deep,

FIG. 116.

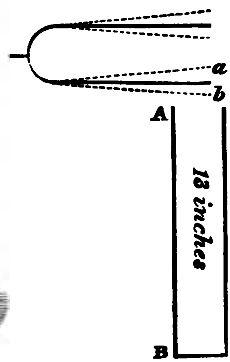

FIG. 117.

and we have found in Art. 219 that a fork making 256 vibrations per second sends out waves 52½ inches long, which very accurately confirms our reasoning.

Fig. 118 represents a piece of apparatus often used to illustrate resonance. It consists of a bell, best sounded by drawing a violin-bow across its edge, and beside it a tube with a movable bottom that has been adjusted to the right depth for the bell. While the tube is

[1] Pronounced sink′rō-nus; derived from the Greek, and meaning *happening at the same time*, or *simultaneous*.

at some distance from the bell the latter sounds feeble, but when we slide the tube up close to it the bell sounds surprisingly strong. Move the tube back and forth, and notice the changes.

The murmuring sound heard in a hollow shell when placed close to the ear is due to resonance. Tyndall says, " Children think they hear in it the sound of the sea. The noise is really due to the reinforcement of the feeble sounds with which even the stillest air is pervaded, and also in part to the noise produced by the pressure of the shell against the ear itself."

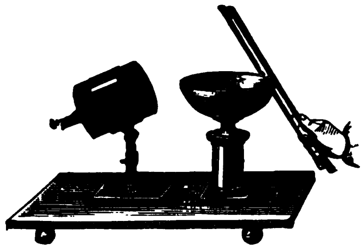

FIG. 118.

Questions.—When the air has a temperature of 62°, what is the length of the tube that will resound best to a fork vibrating 480 times per second? *Ans.* 7 inches. What to one vibrating 280 times per second?

Sound travels nearly four times as fast in hydrogen as in air. Would a column of hydrogen have to be longer or shorter than a column of air to be synchronous with a certain tuning-fork?

227. **The Two Classes of Musical Instruments.**—Most of the musical instruments are either stringed instruments or wind instruments. The piano and violin are the most common stringed instruments. The music of all of this class of instruments is made by the vibrations of strings, generally reinforced by the sympathetic vibrations of sounding-boards. In wind instruments tubes full of air are in some way set to vibrating, and these bodies of air give out the sounds. Pipe- and cabinet-organs, flutes, horns of all kinds, are wind instruments.

228. **Interference of Sound.**—We have learned (Art. 159) that in water-waves, when the highest part of one wave meets the lowest part of another of the same size, the two waves neutralize each other and produce smooth water. In the same way, when the condensed part of one sound-wave meets the rarefied part of another, silence is produced.

Experiment 71.—Sound a tuning-fork, hold it upright a short distance from the ear, and roll it slowly around between the thumb and the finger. Its sound will grow fainter, almost or entirely die out, then grow strong again, and so on as it continues sounding.

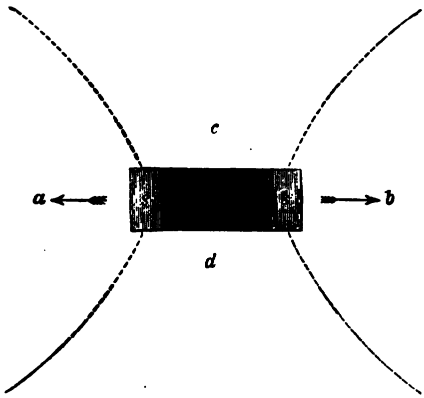

Fig. 119.—Interference of Sound, shown with a Tuning-Fork.

Fig. 119, which represents the ends of the fork, will help to make the cause of this clear. When the prongs are moving outward, there are condensations at *a* and *b*. But, as the air will rush in from the sides to fill the partial vacuum caused by the prongs, there will be rarefactions at *c* and *d*. Along the dotted lines the condensations and rarefactions meet and destroy one another. These are the lines of silence. When the prongs move back again, they will drive the air out at the sides and cause condensations at *c* and *d*, while at *a* and *b* there will be rarefactions, and there will be the same interference along the dotted lines as before.

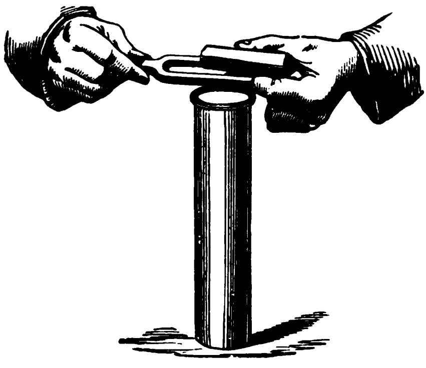

Fig. 120.

In the experiment just described, the fork must be held close to the ear; but by reinforcing the sound of the fork with a resonating-jar it may be heard all over a room. If the vibrating fork be slowly rotated as it is held over the jar, the alternations of loud sounds and silence will be very striking. If the fork be held in the position of silence, and a pasteboard tube be slipped over one prong, as shown in Fig. 120, the

sound will swell out as loud as ever. The vibrations of the uncovered prong are protected from the vibrations of the other, and are no longer quenched.

229. How the Vibrations of the Air-Columns are excited in Wind-Instruments.—Fig. 121 shows a complete and a sectional view of an organ-pipe from a pipe-organ or large church-organ. The air is forced up from below by a bellows, and, rushing against the sharp edge of an opening in the pipe, is thrown into vibrations, which communicate themselves to the column of air in the pipe. It is much like an ordinary willow whistle. In a cabinet-organ the air is set in motion by the vibration of *reeds*. A reed is a strip of brass, fastened only at one end, and arranged so as to vibrate in an opening which it almost fills. There is a reed of a different pitch for every key, and pressing down that key opens the way for the air to pass from the bellows to its reed. The reed is made to vibrate by forcing air from a bellows through the opening around the reed. The vibration of the reed sets the air about it in motion. The melodeon, which has been almost superseded by the cabinet-organ, also produces its music by reeds of this kind, and in a very similar way. (Fig. 122.) The accordion is almost literally a hand cabinet-organ, with bellows and reeds. The common mouth-organ is a reed instrument, and its reeds can easily be seen.

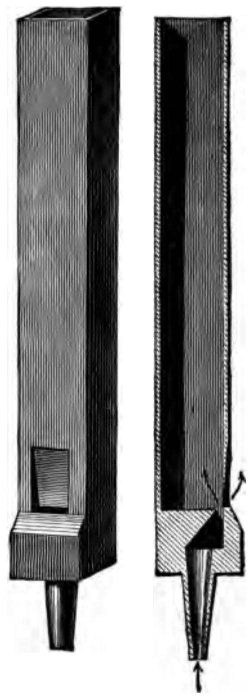

FIG. 121.—ORGAN-PIPES.

Experiment 72.—Take a piece of wheat- or rye-straw, and slit a tongue in it down to a joint, as shown in Fig. 123. This tongue is a reed, and the whole is a simple reed instrument. Blow into the open

end, and note the pitch. Cut an inch or two off the open end and blow again; the pitch is higher. Cut off another piece; the pitch is

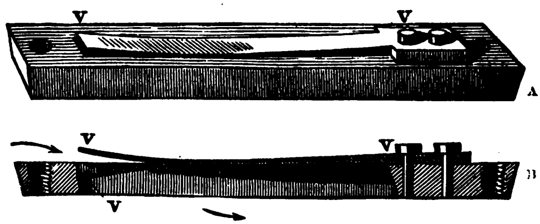

FIG. 122.—CABINET-ORGAN REEDS.

still higher. Careful experiments show that, so far as length is concerned, the law of the sound-vibrations of a column of air is the same as those of a string: *the number of vibrations of a column of air is inversely proportional to its length.*

FIG. 123.—REED MADE OF WHEAT-STRAW.

The clarionet has a wooden reed in the mouth-piece. The flute and the fife are played by blowing against the sharp edge of an opening in the side of the tube. The vibrations are caused very much in the same way as in the pipe-organ, and in the same way as when one whistles in a key.

FIG. 124.—THE VOCAL CORDS.

In a cornet or a horn the lips of the player, pressed against the mouth-piece, act as reeds.

230. **The Human Voice.**—The voice is produced in the upper part of the windpipe: the "Adam's apple" marks the place. Fig. 124 shows the vocal apparatus as looked down upon by means of a laryngoscope.[1] *o* is a slit through

[1] Pronounced la-ring′go-skōp. A pair of mirrors so arranged as to show this part of the throat.

which the air passes to and from the lungs. On either side of this is a membrane, *v*, *v*, projecting from the sides of the windpipe. These membranes are called the *vocal cords*, although they are not cords at all. In ordinary breathing these cords are loose and close to the sides of the windpipe, leaving a wide opening between them. But when we wish to make sounds, they are, by muscular action, stretched tight and brought close together, so as to leave only a narrow slit between them. The air from the lungs passing between them sets them in vibration, and their vibrations produce the sounds of the voice, just as the reeds of a cabinet-organ produce sound. *The human voice is a reed wind-instrument.*

The vocal cords can only make sounds of different pitch and loudness. The resonance of the cavity of the mouth and nose, varying with its shape, changes the sounds of the vocal cords into the distinct vowels and consonants. The pitch of one's voice depends upon the length and thickness of the vocal cords. The ordinary tones of women's voices produce more than twice as many vibrations per second as those of men's voices (Art. 218).

Experiment 73.—Notice that women or girls, and boys whose voices have not changed, show no Adam's apple in the neck, but that it is prominent in men, and especially in men with bass voices: why is this?

Experiment 74.—Get from a butcher the upper part of the windpipe of a hog or other slaughtered animal, cut it open from front to back, and examine the vocal cords. They are very much like yours. You will see what will look like *two* pairs of cords. The lower ones are the true vocal cords; the upper ones perhaps serve to modify the sounds which the lower ones alone produce.

231. **Vibrations of Strings in Parts.**—Experiment 75.—Touch the middle of the sonometer wire with your finger, or with a feather, and draw the bow across the middle of *one half*. The middle point which was held by the feather is stationary, but each half of the wire is vibrating. Set a rider, made by folding a bit of paper into the shape of a V, upon the middle of either half, it is thrown off. Set it upon the middle of the wire, it stays there: why?

Experiment 76.—Again, touch the wire at one-third the distance from one end, and draw the bow across the middle of *one third*. The wire will vibrate in thirds. Test the points of greatest vibration and of no vibration with the riders. In the same way the wire may be made to vibrate in fourths, fifths, etc.

The parts of the wire which we have made to vibrate are called *segments*. The points between the segments, where there was no motion, are the *nodes*. When a string is thus vibrating in parts only, its pitch is higher than if

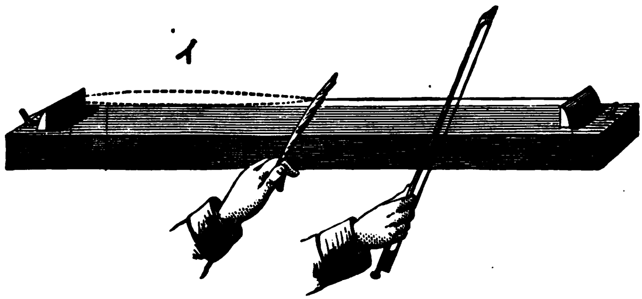

FIG. 125.—STRING VIBRATING IN HALVES.

it were vibrating as a whole, for, according to the first law of vibrating strings, when it vibrates in halves each segment vibrates twice as fast as the whole string would; when in thirds, each segment vibrates three times as fast, etc. When a string vibrates in parts, the segments are always

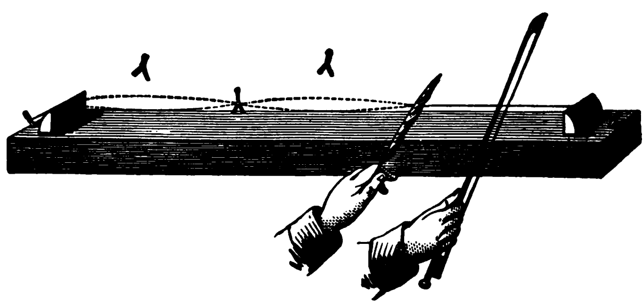

FIG. 126.—STRING VIBRATING IN THIRDS.

equal; each is an exact division of the whole string. And again, when a string vibrates in parts, *any two consecutive parts are always moving in opposite directions.* Thus, in Fig. 125, while one half moves up the other half is coming down;

and in Fig. 126 the two end segments are swinging in one direction while the middle one swings in the other.

232. **A String may vibrate in Parts and as a Whole at the Same Time.**—If the wire of the sonometer be plucked near one end, it will vibrate in parts and as a whole at the same time. Fig. 127 shows a string thus vibrating as a

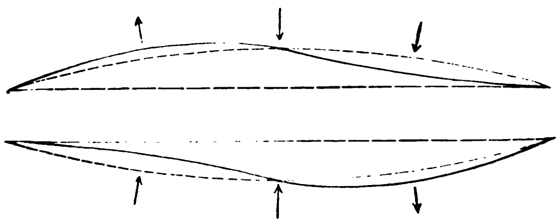

Fig. 127.—String vibrating as a Whole and in Halves.

whole and in halves. The middle arrows show the direction of the whole string, the others show the smaller and quicker vibrations of the halves. In the same way it may, while vibrating as a whole, be also vibrating in thirds, fourths, etc. And it may even be vibrating as a whole, in halves, thirds, fourths, etc., *all at the same time.*

233. **Vibrations of Air-Columns in Parts.**—The air in an organ or other pipe may vibrate as a whole or in parts, or as a whole *and* in parts at the same time, just as a string may.

Experiment 77.—Take a tube of glass or other material, about 18 inches long and from a quarter to half an inch in diameter, close one end with the finger, and blow rather gently across the other, and you hear a low note, the lowest or the *fundamental* note of your tube: the air-column is vibrating as a whole. Blow again and strongly, and you make a much higher note. The air-column is vibrating in segments. Try the same experiments with the lower end of the tube open: the results are like the others.

In trying the above experiment you must have noticed that the lowest note of the open pipe was much higher than the lowest note of the closed pipe. This is because the air in a pipe open at both ends can never vibrate as a whole: there is no bottom to the pipe to

send the wave back again. The lowest note that such a pipe can give is when it is vibrating in halves; then the two waves meet each other at the middle and turn each other back. Just at the middle there is no motion of the particles: there is a node there. A pipe open at both ends gives the same pitch as one of half its length which is closed at one end. In fact, it is just the same as two closed pipes with the closed ends together. The keys in horns and the finger-holes in flutes, etc., enable the player to change the nodes and the lengths of the vibrating columns of air, and therefore to vary the pitch of his tones.

234. **Overtones.**—When a whole string, or a column of air, and its various parts are vibrating together, the vibrating parts also produce tones, higher in pitch, of course, than that of the whole string. These are called *overtones.* The overtones cannot usually be distinguished from the fundamental tone by ordinary ears, and so they do not affect the pitch of the sound, which is that of the string as a whole; but they do change the *character* of the tone, as we shall see hereafter.

Helmholtz[1] has invented an instrument to enable us to detect the overtones in a compound sound. It is called a *resonator*, and is shown in Fig. 128. This is made of just the size to be resonant to the sound made by *halves* of a certain string. When the string is sounding as a whole, and also in halves, the small end of the resonator is put into the ear, and by its resonance it so strengthens the sound of the halves that they can be distinctly heard. Another resonator of different size will strengthen the sound of the thirds enough to be heard, another the fourths, and so on. By having a whole set of these resonators, all the overtones in a compound sound can be dis-

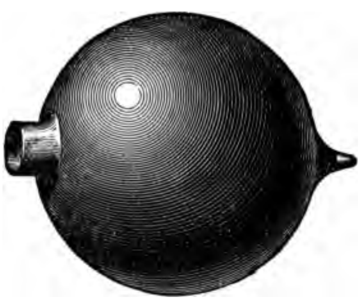

FIG. 128.—HELMHOLTZ'S RESONATOR.

[1] H. L. F. Helmholtz (1821-1894), Prof. of Physics in the University of Berlin, and one of the greatest scientists of this or any other age.

tinguished. These instruments show that the sounds of almost all our musical instruments are very complex. The strings of pianos and violins, the reeds of organs, etc., besides sounding as wholes, are also vibrating in halves, thirds, fourths, fifths, and often many more parts. The human voice has many overtones.

235. Manometric Flames.—Koenig, an instrument-maker of Paris, has devised an apparatus which shows the effects of the overtones very beautifully. It consists of two parts, one of which is shown in Fig. 129. *m* is the mouth-piece of a tube, across the other end of which is stretched a piece of india-rubber, *r*. *f* is a gas-burner, fed by the tube *g*. The gas-tube is separated from the other only by the thin sheet of rubber. The vibrations of the voice sounding at *m* set the rubber partition to vibrating, and drive out the gas in puffs. These cause changes in the height of the flame, but they are too rapid to be noticed, and the gas-flame looks to the eye to be steady. But when a square box having its four sides covered with mirrors (Fig. 130) is rapidly rotated in front of the flame, its changes can be seen.

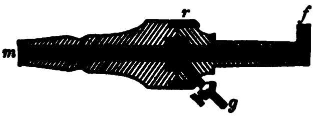

FIG. 129.

FIG 130.

Fig. 131 shows the various forms that may be produced. 1 shows the reflection of the gas-flame when the mirror is stationary. 2 is the reflection when the mirror revolves without any sound being made in the tube. 3 is a low, simple sound, with no overtones. 4 is a higher simple sound, but with no overtones. In 5 the first overtone (in halves) is sounding with the fundamental, only every other vibration of the overtone being seen, the others are united with the fundamental. In 6 the second overtones (in thirds) are vibrating with the fundamental.[1]

Almost any sound can be analyzed with this instrument, making very interesting and curious experiments.

236. Character of Sound.—Besides pitch and loudness,

[1] 3 and 4 can be produced by singing into the tube *oo* as in pool; 5, by singing *a* in B♭ (second space below the treble clef); 6, by singing *a* in the note F. (From Mayer's *Sound*, p. 160.)

sound has another quality. A piano, a violin, and a human voice may all sound with the same pitch and the same loudness, and yet they sound very unlike; any one can tell them apart. This quality which distinguishes different

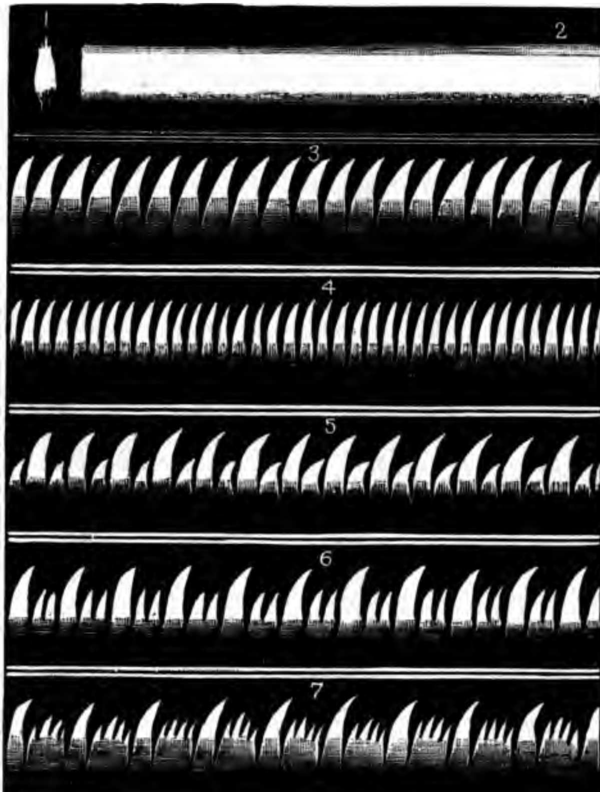

FIG. 131.—VIBRATIONS SHOWN BY MANOMETRIC FLAME APPARATUS.

kinds of sounds from one another is called *character*, or *timbre*. *The character of sounds has been found to be wholly due to the overtones.* If a sounding body is vibrating only *as a* whole, and not in parts, or if while vibrating as a

whole only the halves, and perhaps the thirds, are also vibrating, its sound is pure or simple. This is the case with a tuning-fork or an organ-pipe. But if a sounding body while vibrating as a whole is also vibrating in many different divisions at the same time, its sound, though of the same pitch as the other, has a very different character: it is more "brilliant." The sounds of the violin, horn, and cymbals are good examples.

237. The Three Qualities of Sound.—The *pitch* of sound depends wholly upon the rapidity of the vibrations. The *loudness* of sound depends wholly upon the amplitude, or length of swing, of the vibrations. The *character* of sound depends upon the number of overtones, or vibrations of parts, that are mingled with the fundamental sound. All the difference between musical sounds of any kind is made by one or more of these three qualities.

238. Vibration of Plates in Parts.—Experiment 78.—Get a piece of good window-glass about six inches square, rub its sharp edges smooth with a grindstone. Clamp it in the middle with a vise like that shown in Fig. 132, which has been fastened to the edge of a table by the lower screw. Scatter writing-sand over the glass, and draw a well-resined heavy bow across the edge near one corner, while touching the middle of another edge with the finger. The sand will arrange itself in lines as in Fig. 133. Again, touch the glass at one corner, and draw the bow across the middle of one edge, Fig. 134 will be produced.

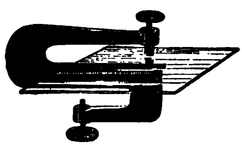

Fig. 132.

These are called *Chladni's*[1] *Figures.* The finger holds the glass still where it touches it, and starts a *node* there. The glass vibrates in parts, and shakes the sand gradually to the nodal lines between the vibrating parts where there is no vibration. As with strings and columns of air, any two consecutive segments are always vibrating in opposite directions. Fig. 135 shows some of the many sand-figures

[1] E. F. F. Chladni (kläd'ne), 1756–1827,—a German natural philosopher.

that have been thus produced by touching and bowing the plate in different ways.

Bells, gongs, cymbals, etc., vibrate in parts as these plates

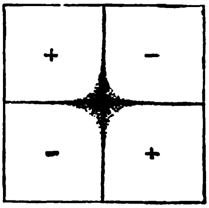

FIG. 133.

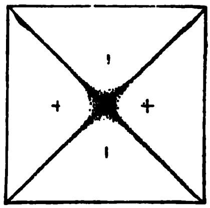

FIG. 134.

do, and both their fundamental tones and their overtones are due to such vibrations.

SECTION IV.—MUSIC.

239. **The Scale.**—There is a regular succession of eight sounds of increasing pitch used by all persons in singing or playing any musical instrument, called the *scale.* The names of these sounds as they are used in singing are *do, re, mi, fa, sol, la, si, do.*[1] In *instrumental music* the sounds of the scale are denoted by the following letters: C, D, E, F, G, A, B, C. The first or lower *do*, or C, is called the *key-note*, or *fundamental* note, of the scale.

Almost all who study this book are familiar with the scale, and can sing it for themselves. If any cannot, they may hear it by striking eight successive white keys of a piano or organ, beginning with C.

240. **The Derivation of the Scale.**—To derive the scale, let us use our sonometer again. It will be convenient to have the wire 30 inches long to start with. If it is longer than that, we may use that much of it by putting a bridge under it, 30 inches from one end.

To produce *do*, sound the whole string.

[1] Pronounced dō, rā, mē, fah, sōl, lah, sē, dō.

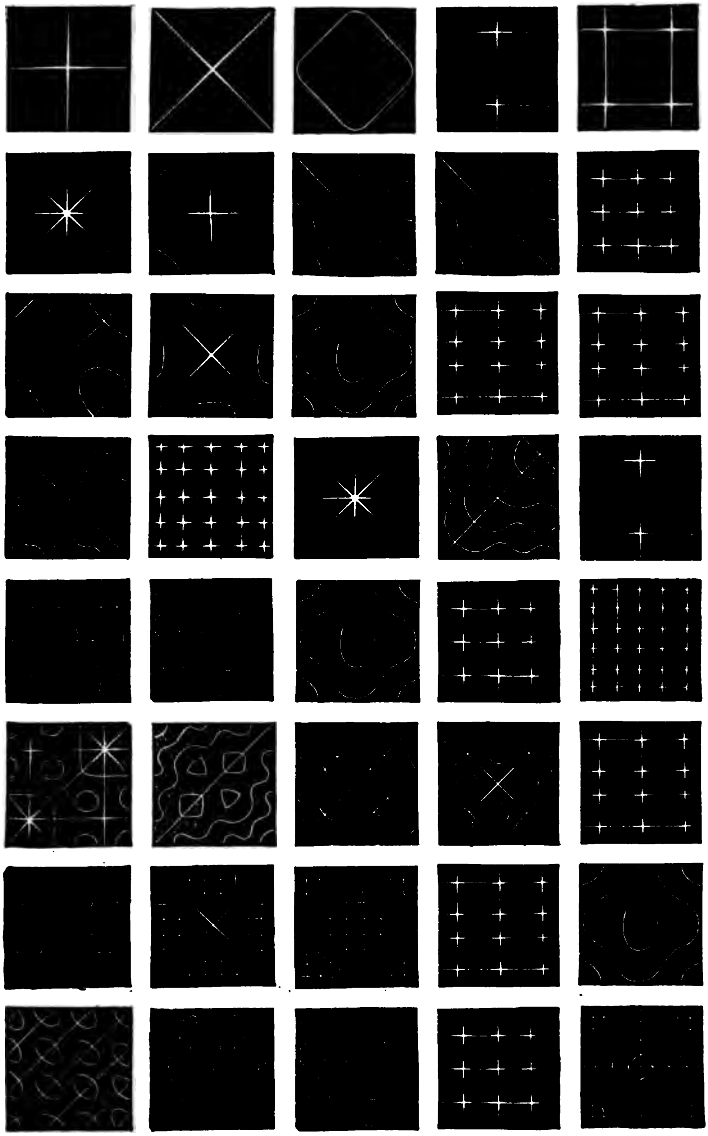

FIG. 135.—SAND-FIGURES.

To produce *re*, move the bridge so as to make the wire $\frac{8}{9}$ *as long as at first* ($26\frac{2}{3}$ inches), and sound it.

To produce *mi*, move the bridge so as to make the wire $\frac{4}{5}$ *as long as at first* (24 inches), and sound it.

To produce *fa*, move the bridge so as to make the wire $\frac{3}{4}$ *as long as at first* ($22\frac{1}{2}$ inches), and sound it.

To produce *sol*, move the bridge so as to make the wire $\frac{2}{3}$ *as long as at first* (20 inches), and sound it.

To produce *la*, move the bridge so as to make the wire $\frac{3}{5}$ *as long as at first* (18 inches), and sound it.

To produce *si*, move the bridge so as to make the wire $\frac{8}{15}$ *as long as at first* (16 inches), and sound it.

To produce *upper do*, move the bridge so as to make the wire $\frac{1}{2}$ *as long as at first* (15 inches), and sound it.

1, $\frac{8}{9}$, $\frac{4}{5}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{3}{5}$, $\frac{8}{15}$, $\frac{1}{2}$, are the proportionate lengths which a string (whose tension is unchanged) must invariably have to produce the common scale. The eight sounds are called an *octave*.[1]

241. **The Number of Vibrations of the Notes of the Scale.** —According to the first law of vibrating strings, the number of vibrations of a string is *inversely* proportional to its length. Therefore, if we invert the fractions given above, we have the relative numbers of vibrations per second which are produced when the successive notes of the scale are sounded. They are as follows: 1, $\frac{9}{8}$, $\frac{5}{4}$, $\frac{4}{3}$, $\frac{3}{2}$, $\frac{5}{3}$, $\frac{15}{8}$, 2. It will be noticed that the upper *do*, or C, is produced by exactly twice as many vibrations as the lower one. This note is called the *octave* of the one below, and this use of the word octave is rather more common than the use given in the preceding paragraph. When the octave of a note is sounded with the voice or with any instrument, twice as many vibrations are invariably produced.

If lower *do* is produced by 24 vibrations per second, how many vibrations will produce the succeeding notes of the scale?

[1] From the Latin *octavus*, meaning eighth.

242. The Repetition of the Scale.—In any scale the upper *do* is the *lower do*, or key-note, of the next octave. The sounds of this octave are denoted by the same names or letters as those of the octave below. The notes of this octave are produced by strings having the same proportion to the length of the string sounding its key-note as the notes of the octave below had to theirs. And the ratios of the numbers of vibrations are just the same as before. In the same way the scale is repeated in every seven notes *above* or *below* the one we have started with to the upper and lower limits of audibility (Art. 218). Every note, no matter how made, is produced by *twice* as many vibrations as the note of the same name in the octave below, *four* times as many as the one in the *second* octave below, etc.

Questions.—The upper *do* produced according to the directions given in Art. 240 was made by the vibrations of a wire 15 inches long: what must be the successive lengths of the wire to produce the notes of the octave above, of the second octave above, of the octave below?

If the key-note of a scale is produced by 24 vibrations per second, how many vibrations will be necessary to produce the notes of the octave above? of the second octave above? How many of the notes of the octave below can be produced? Why can they not all be produced?

243. The Fixing of the Pitch of the Key-Note.—Any pitch whatever may be taken for the key-note, and the different notes will range above or below this, according to the laws just given.

One person may sing a piece of music using a key-note of a certain pitch. A second person may take for his key-note the pitch which the first gave to *re* and sing the same piece through. Each of his sounds will of course be one note higher than those of the other singer. A third singer may take the pitch of the *sol* of the first for his key-note; and so on. This is very noticeable when different persons start tunes without the aid of instruments. The natural limits of the human voice, however, confine us in our choice of the pitch of the key-note to rather narrow limits, varying according to the compass of the singer's voice and the range of the piece of music sung. Leaders of vocal music often use tuning-forks in order to get the most suitable pitch.

Piano-tuners use tuning-forks or whistles, which always make a

certain known number of vibrations per second, and tune pianos by them. In the best American pianos middle C makes 268 vibrations per second.

244. Intervals between the Notes of the Scale vary.—The following numbers are the answers to the problem given in Art. 241, and are the *relative* numbers of the vibrations of the notes of any scale,—viz.: $\overset{\text{do}}{24}$, $\overset{\text{re}}{27}$, $\overset{\text{mi}}{30}$, $\overset{\text{fa}}{32}$, $\overset{\text{sol}}{36}$, $\overset{\text{la}}{40}$, $\overset{\text{si}}{45}$, $\overset{\text{do}}{48}$. *Re* is produced by $\frac{3}{24}$ or $\frac{1}{8}$ more vibrations than *do*, *mi* by $\frac{1}{9}$ more than *re*, *fa* by $\frac{1}{15}$ more than *mi*; from *fa* to *sol* and from *la* to *si* the increase is again $\frac{1}{8}$, from *sol* to *la* $\frac{1}{9}$, and from *si* to *do* $\frac{1}{15}$ again. Thus we see that in three of the intervals there is an increase of $\frac{1}{8}$ in the number of vibrations, in two of the others an increase of $\frac{1}{9}$, and in the remaining two an increase of only $\frac{1}{15}$. The five longer intervals are called *whole tones*, although they are not all of the same length, as we have seen. The two shorter ones are called *half tones*, although they are really longer than half of any of the whole tones, as you may see by comparing $\frac{1}{15}$ with the halves of $\frac{1}{8}$ and $\frac{1}{9}$. In every common scale the intervals between the notes are in exactly these proportions, and their order never varies.

A scale is sometimes used which is made by inserting an extra note in the middle of each whole tone: this gives us thirteen notes in the scale, all *about* the same distance apart. This is called the *chromatic*[1] *scale*. But it is not natural to sing the scale with half tones anywhere else than between the third and fourth and the seventh and eighth notes, so that few people can sing the chromatic scale. When any other than the natural half tones are wanted in a piece of music, the composer usually *transposes the scale;* that is, he starts with his key-note a little higher or lower than the *do* of the ordinary or *natural* scale, and thus brings the regular half tones just where he wants a half interval between two of his notes to come.

245. Temperament.—If a piano or an organ is tuned according to the natural scale, from C to D there is an increase of $\frac{1}{8}$ in the number

[1] From the Greek word meaning *color*, because these inserted tones used to be represented in colors.

of vibrations, from D to E of $\frac{1}{9}$, from E to F of $\frac{1}{15}$, etc. If, then, one should play upon such an instrument a piece of music in which the key-note is D, the interval between that and the next key would be only $\frac{1}{9}$ instead of $\frac{1}{8}$, so that it would not give correctly the second note of the scale. The next key, $\frac{1}{15}$ higher, would not be a correct half note between the second and third notes of our scale, as it should be, and so on through the scale. Not one interval in our scale would be correct. The same would be true of every other scale; none but the one in which the instrument was tuned could be played upon it correctly. This is partly corrected by the tuner distributing these errors equally over all the scales. This distribution of these errors is called *temperament.* The result is that no scale on a piano or an organ is absolutely correct, but the errors in any are so slight that most persons cannot notice them. If the instrument were tuned correctly for any one scale it would sound very badly when played in any of the others. The piano and the organ, therefore, are not perfect instruments, and can never make perfect music. But in the violin and the flute the pitch is controlled by the player, and they may in the hands of a skilful player produce perfect music.

246. **Beats.**—**Experiment 79.**—On a piano, or, better still, on a cabinet-organ, sound together the lowest key and the black key next to it. Mingled with the sounds of the two keys you will notice a peculiar quivering sound. These quivers, or bursts, of sound, which on the organ or piano are entirely too rapid to be counted, are called *beats.*

To understand the cause of these beats, we must go back to the interference of sound-waves, about which we learned in Art. 228. Let us suppose that two sound-waves, one vibrating 100 times per second and the other 101 times per second, start out together. At the start their condensations will coincide; they will strengthen each other and make a louder sound than either would alone. After half a second one is at the end of exactly fifty vibrations, and is, we may suppose, at its greatest condensation, but the other is at the end of fifty and a *half* vibrations, so that it must be at its greatest rarefaction. There the two sounds would destroy each other. At the *end* of the second the 100th condensation of one coincides with the 101st condensation of the other, and they strengthen each other

again. These will be repeated as long as the sounds can be heard. These alternate strengthenings and quenchings of the sound cause the beats.

It is clear that in the illustration just taken there would be one beat each second; and the same would be true with any two sounds, one of which vibrates once oftener than the other in a second. If one has 100 and the other 102 vibrations per second, at the middle one wave is at the 50th and the other at the 51st condensation. These strengthen each other *twice* in each second. Again, if one vibrated 100 and another 105 times per second, the 20th condensation of one would strengthen the 21st of the other; the 40th of the one, the 42d of the other; the condensations coincide five times, or there are five beats, each second. The number of beats in a second is equal to the difference in the number of vibrations which the two sounds make per second.

Beats can be made much better than on a piano or an organ by using two large tuning-forks of the same pitch, mounted on sounding-boxes, and loading one of them with a little wax. By increasing the wax the beats are made more frequent.

Beats are always produced when two notes of different pitch are sounded together. Generally they cannot be noticed, but nevertheless they have a most important effect upon the sound, as we shall see in the next paragraph.

247. **Harmony and Discord.**—"If, towards sunset, you walk on the shady side of a picket-fence, flashes of light will enter your eye every time you come to an opening between the pales. These flashes, coming slowly one after the other, cause a very disagreeable sensation in the eye. Similarly, if flashes or pulses of sound enter the ear, they cause a disagreeable sensation."[1] When two notes of different pitch are sounded together, beats are always produced. If these are *very* slow, the effect is not particularly disagreeable, but if they are numerous, as when any two contiguous keys of a piano or an organ are sounded, they produce a harsh sound, which we all recognize as a *discord*.

"But if the flashes of light or beats of sound succeed

[1] Mayer's *Sound*, pp. 174, 175.

skull, and is filled with a watery fluid. The nerve of hearing runs from the brain to the labyrinth, and there divides up into thousands of microscopic branches, which stick out like bristles from the sides of the labyrinth into the liquid which fills it.

250. **How we Hear.**—The sound-vibrations enter the ear, strike the tympanum, and set it in vibration. Its vibrations are carried across the drum of the ear by the chain of little bones, and also by the air there, and set the membrane covering the openings into the labyrinth into vibration; and this communicates its vibrations to the liquid within. The tiny bristles which project into the liquid are of different lengths and thicknesses, and it is supposed that these are *tuned* each to a different pitch, and, in all, to all the pitches that are audible. It is likely, then, that the waves in the liquid which are produced by sound of a certain pitch set to vibrating the bristle which is tuned to the same pitch, and that the nerve-thread attached to this bristle conveys this impression to the brain and to the mind. When the sound contains overtones as well as the fundamental, each element of the sound must set in motion the bristle tuned to its pitch, and the combined impressions of these give us the true impression of the sound.

Exercises.—1. Why does touching a call-bell with your finger silence it?

2. There is believed to be no atmosphere of any kind on the moon: would this have any effect on sounds there?

3. Your pulse probably beats about 80 times per minute. Suppose that on a day when the temperature is at the freezing-point you count five beats of your pulse after you see the escaping steam of an engine-whistle, and before you hear its sound: how far off is the engine? *Ans.* $4087\frac{1}{2}$ feet.

4. Suppose that on a summer day, when the thermometer stands at 80°, you count four beats of your pulse between a flash of lightning and the first sound of the thunder: how far off is the lightning?

5. A leader of a room full of singers is at one end of the room, which is 60 feet long. If the temperature of the room is 68° (which is about what it ought to be), how much will the words of the singers on the back seat seem to the leader to be behind his own? *Ans.* $\frac{60}{1130}$ second.

6. What is the temperature of the air when the velocity of sound is 1150 feet per second? *Ans.* 92°.

7. Until recently the velocity of sound was always given as 1142 feet per second: what must have been the temperature when that result was obtained?

8. How far off is a barn when the echo of your voice comes back to you after you have counted three beats of your pulse, the temperature being at 60°?

9. The bell in the clock-tower at Westminster Abbey, London, is 300 feet above the ground: find the time sound takes to pass from the bell to a point on the ground 400 feet from the foot of the tower, the temperature being the same as in the last problem? *Ans.* $\frac{250}{559}$ second.

10. A certain string vibrates 100 times per second: find the number of vibrations of another string which is twice as long and weighs four times as much per foot and is stretched by the same force. *Ans.* 25.

11. A musical string vibrates 400 times per second: what takes place when the string is lengthened or shortened without altering the tension? when the tension is made greater or less without altering the length?

12. A tuning-fork vibrates over a jar 15 inches deep, and a strong resonance is produced: what is the rate of the fork's vibrations if the temperature is such that sound travels 1120 feet per second?

13. If *do* vibrates 264 times per second, how many vibrations in *mi* above it? in *sol*? in the upper *do*?

14. If *do* vibrates 264 times per second, how many vibrations produce *re*, *si*, and *fa* in the octave below?

15. Draw on the blackboard a line 30 inches long, and above it draw lines of the right proportions to represent strings which would give the notes of the octave above.

16. Middle C of a piano vibrates 272 times per second. In a seven-octave piano the lowest key is the fourth A below middle C, and the highest is the fourth A above it: what are the rates of vibrations of these two keys?

17. In a seven-and-one-third-octave piano the lowest key is the same as before, but the highest is the fourth C (four octaves) above middle C: how many more vibrations per second will the highest key of this piano make than the highest one of the other?

18. If *re* is produced by 216 vibrations per second, how many will produce *do* below? *re* below? *la* above?

19. Over how many octaves does the range of human hearing extend?

20. How many beats per second will there be when middle C and G above are sounding together on a piano? how many when B above is sounded with middle C?

21. If corresponding keys towards the upper end of the key-board be sounded together, will the beats be the same as in the last problem? How will it be if they are taken in the lower end of the key-board?

SUMMARY OF CHAPTER V.

All sound is produced by vibrations.

The *sensation* of sound is due to vibrations made in the brain, being carried to it by the auditory nerve.

Sound-vibrations are ordinarily carried to the ear by the air, though other gases, and most solid and liquid substances, convey them as well.

The vibrating particles producing sound-waves move forward and backward in the direction in which the sound is propagated.

The velocity of sound in air at the freezing-point is about 1090 feet per second.

The *loudness* of a sound depends upon the *length* of the vibrations producing it; the *pitch* upon the *rapidity* of the vibrations; the character or *timbre* is due to the mingling of *overtones* with the fundamental note.

The air frequently contains *acoustic clouds*, which are detected only by their interference with the free passage of sound.

A *musical sound* is produced by a series of vibrations following one another at *regular intervals*, and rapidly enough to produce a continuous sensation on the brain.

The rapidity of vibration of strings and wires is *inversely* proportional to the *length* and *square root of the weight*, and *directly* proportional to the *square root of the tension.*

The rapidity of vibration of a column of air is inversely proportional to its length.

Musical instruments are of two classes: one class employing vibrating strings or wires; the other, vibrating columns of air.

A string or a column of air may vibrate in parts. It may also vibrate as a whole and in parts at the same time.

In the latter case the vibrations of the *parts* produce *overtones.*

When any body is vibrating in parts, contiguous parts are always in *opposite phases of vibration*, and where they join is a *node.*

In any octave, the numbers of the vibrations producing the successive notes of the scale are in the following proportion: $1, \frac{9}{8}, \frac{5}{4}, \frac{4}{3}, \frac{3}{2}, \frac{5}{3}, \frac{15}{8}, 2$.

Beats may follow one another with such rapidity as to produce additional notes. These produce *harmony* or *discord*, depending on how they fit the original notes.

CHAPTER VI.

LIGHT.

I.—THROUGH UNIFORM MEDIA.

251. **Sources of Light.**—Light comes to us from the sun by day and from the moon and stars by night. It is produced on the earth by combustion, by friction, by electricity, and by phosphorescence. Light from combustion is familiar in all fires. Light from friction may be seen by rubbing two pieces of white sugar together in the dark. The light from meteors (shooting-stars) is produced by the friction of small bodies moving with great velocity through the atmosphere. Light from electricity is visible when a cat is stroked vigorously in the dark. The lightning and probably the aurora are electric. Light from phosphorescence is often seen in decayed wood, in "luminous paint,"—a salt of calcium which glows when taken from a light place to a dark one,—and in a fire-fly.

Astronomy tells us that the sun is one of the stars, and that the moonlight is only reflected sunlight. Hence we may say that we have one celestial source of light,—the stars,—and four terrestrial sources,—combustion, friction, electricity, and phosphorescence.

252. **Cause of Light.**—In all these cases the light is produced in the same way. The particles of the body from which the light comes are put in extremely rapid vibration. The surrounding ether catches up these vibrations and carries them along like waves in water till they reach the eye of the observer.

253. **The Sensation of Light.**—In the retina (Art. 294) of the eye are many little nerve-fibres which take up these

vibrations and carry them to the brain, giving us the *sensation* of light. This is true whether the eye receives simply a *bright impression*, as from a lamp-flame or from the sun, or whether it *sees objects*—men, houses, books—which are illuminated by daylight or lamplight. *All impressions on the nerve of sight are made by light.*

254. **Light-Waves.**—Referring again to Art. 159, the parts of the rope in producing the waves moved up and down, perpendicular to the floor, and as a consequence the waves moved up and down. It would have been difficult for us to produce them in any other direction. The same is true of water-waves. As, in these cases, the individual particles move perpendicularly, while the wave moves horizontally, we speak of the waves as vibrations perpendicular to the direction of propagation,—*i.e.*, the direction in which the wave travels. The same is true of light-waves, they are perpendicular to the direction of propagation. But while the vibrations in water-waves are *up and down* only, light-waves *know no up and down.* In the water-wave and the rope-wave, the force starting the wave may be considered as a lifting force. Particles lifted by this force are soon drawn down again towards the earth's centre by gravity. Any waves produced in part by gravity, in a substance on which gravity acts, must be up and down. The ether which carries light-waves has no weight (Art. 44), consequently is not influenced by gravity, and moves as freely away from the earth as towards it and as freely horizontally or obliquely as in either of the other directions.

FIG. 157.—CRYSTAL OF TOURMALINE.

255. **Vibration in all Planes.**—The above is best shown by means of a piece of tourmaline. If possible, procure a

piece from an optician and verify the statements made now and hereafter in reference to its action. While about it, get *two* pieces alike; they will come of use. Fig. 137 shows the crystal as found in the quarry. Fig. 138 shows the slice cut from the crystal by the optician. Light reaching the tourmaline consists of vibrations in all possible planes. Only those vibrations, however, which are made parallel with the axis of the crystal, or length of the slice, can get through. The tourmaline (unless very thin) quenches the rest.

Experiment 81.—Hold the tourmaline between the eye and the window and slowly rotate it. The light coming through will be dim because of the part quenched, but it will appear *equally bright at all angles with the horizon.* (Fig. 138.) This shows that the light is vibrating in all planes when it encounters the tourmalines.

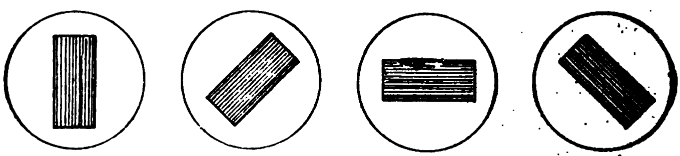

FIG. 138.—TOURMALINE IN DIFFERENT POSITIONS.

A rough illustration of the quenching of all the light-waves by the tourmaline, except those in one plane, might be given by supposing a few parallel bars stood upright an inch apart in a level floor. The waves of a rope would run between any two of the bars if the vibrations were perpendicular to the floor. Vibrations in any other plane would be stopped by the bars.

256. **Polarized Beam.**—A beam of light which has all its vibrations reduced to one plane, as that which has passed through a tourmaline, is called a *polarized* beam. The polarization of light will be treated more fully later in the chapter.

257. **Length and Rapidity of Light-Waves.**—As the rapidity and consequent length of sound-waves varies with the *pitch* of the sound, so the rapidity and length of light-waves varies with the *color* of the light, but they are all very *rapid* and very minute. In the next chapter we shall learn

that radiant heat is carried by ethereal vibrations as light is. The longer, slower vibrations are heat; the shorter, more rapid vibrations are light. When a piece of iron is heated in a coal fire, the particles are set into vibration, and the vibrations grow more and more rapid. They first give us the sensation of heat. This soon becomes more intense than we can bear, and when it has reached about 1000° Fah. the vibrations act on the nerve of sight, and the iron is a *red*

FIG. 139.—IMAGE THROUGH A SMALL HOLE.

glow. It requires about 450 millions of millions of vibrations per second to produce this result. When the iron is at its most intense white heat, there are vibrations at the rate of nearly 800 millions of millions per second. These vibrations are *violet* to our eye, and the mixture of these and all the intermediate vibrations gives the sensation of *white*. The longest light-waves (red) are about $\frac{1}{40,000}$ of an inch long; the shortest (violet) are about $\frac{1}{70,000}$ of an inch.

258. **Light moves in Straight Lines.**—Light-waves are carried forward in straight lines so long as they do not meet with any change in the substance through which they pass. We always recognize this. We assume an object to be in the direction in which we see it,—that the light by which we see it carries the impression to the eye in a straight line. We can test the same fact by an experiment.

Experiment 82.—Arrange three cards by fastening them to blocks so that they will stand upright on a table. Pierce a small hole in each card, and place them so that a stretched string will go straight through all the holes. Now put a lamp in front of the end hole. It will shine through all. But if any of the cards be moved so that the holes are not in a straight line, the light will not shine through.

Experiment 83.—Darken a room, and make a small hole in a shutter opposite a white wall. Over this paste a piece of paper in which a hole is pierced. The outside landscape will be projected on the wall inverted (Fig. 139), for all the rays will cross at the opening. Rays from *a* will move in straight lines to *a′*, and rays from *b* to *b′*. (Fig. 140.)

Experiment 84.—Hold a candle in front of a sheet of cardboard in which a hole is pierced. The candle will be seen inverted on a small screen held beyond the hole.

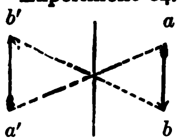

FIG. 140.—LIGHT MOVES IN STRAIGHT LINES.

Experiment 85.—Have made in a temporary window-shutter a number of small openings of different shapes, and let the sun shine through into the room. Receive the image from them on a screen placed at a distance from the holes. These images will all be round, not the shape of the holes. They are images of the round sun.

The same may be seen in the light patches on the ground under a tree, formed by the passage of sunlight through the small openings in the foliage.

259. **Transparent, Opaque.**—The luminiferous (light-bearing) ether appears to exist between the molecules of most—possibly all—substances. The molecules of some substances interfere with the vibrations of the ether, and either stop the waves or send them back, so that the light cannot get through any appreciable thickness of the material. Bodies which thus stop the light entirely are *opaque*. In other substances the ether has much freedom of motion, so that light is carried a considerable distance through them. *Such* substances are called *transparent*. In the space among

the planets, beyond their atmospheres, there is practically nothing to quench light-waves, so that they travel easily thousands of millions of miles. The most transparent glass or water is transparent only in comparatively small thicknesses.

260. **Shadows.**—Shadows are a result of the motion of light-waves in straight lines. If an opaque body be placed between a source of light and the wall, a dark place is shown on the wall, which is due to the fact that the light which would otherwise fall on it is cut off by the opaque body.

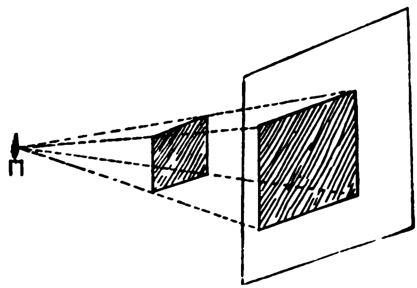

FIG. 141.—SHADOW.

Experiment 86.—Stretch a string from the source of light touching the edge of the shadow; it will touch the edge of the body.

Experiment 87.—Make the body a square, and place it exactly half-way between the light and the wall. Measure the shadow. Its side will be twice the side of the square and hence its area will be four times that of the square.

261. **Law of Light-Variation.**—The last experiment explains an important law. The light which would have been spread over the space occupied by the shadow now is collected on the square, and therefore covers only one-fourth the space. Hence it is four times as intense on the screen as at the wall. The wall is twice as far from the light as the square is, and the intensity is only one-fourth as great. Were the wall three times as far away, the intensity of the light would be only one-ninth as great. The general law is, *Light diminishes in intensity as the square of the distance increases.*

This refers to light from a given source, spread over the surface which it illuminates. It does not apply to the brightness of a light.

lamp, a candle, a star—*as seen by the eye.* The light in the eye is an *image* (see Art. 292) of the lamp- or candle-flame, or star, and the image *decreases in size* with increased distance, just as rapidly as the brightness of light on a plane surface decreases in intensity, so that a *given area* of the retina receives as much light in one case as in another.

Experiment 88.—Take a lantern out-doors on a dark clear night. Set it on a barrel, and take a look at distances of 10, 50, 100, and 1000 yards. No difference in *brightness* will be noticed by the eye. Try *reading a book* by the light of the lantern at these distances!

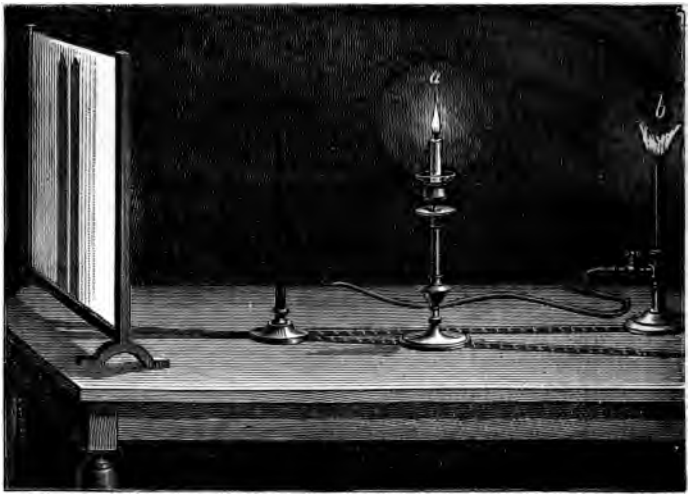

FIG. 142.—PHOTOMETRY.

If the source of light is *large*,—*e.g.*, an engine fire,—it will make a *brighter* spot when we are far enough away to have the image of the *whole grate* on the retina than when we are so close that only a part at a time is imprinted on it. The light of some stars is dim because they are so far away, and the image on the retina consequently so minute, that it is scarcely able to excite the nerve of sight to action. All the statements in this article, and the results of the next, are modified by the fact that *some* light is quenched in its passage through the air.

262. **Photometry.**—We can compare the relative intensities of two lights by the aid of the law stated in the last *article*.

Experiment 89.—Place an opaque body in front of a wall, and arrange the lights so that the two shadows shall be side by side. Move one of the lights backward or forward till the shadows are of the same intensity of darkness. The shadow from *a* is still lit up by *b*, and the shadow from *b* by *a*. If the shadows are equally bright, the intensities of the light given by the two bodies at the wall are the same. Now measure the distance of each light from the wall. The squares of these distances will be the relative intensities of the lights. (Fig. 142.)

263. **Umbra and Penumbra.**—If the source of light, instead of being small, is of considerable size, we shall find that the

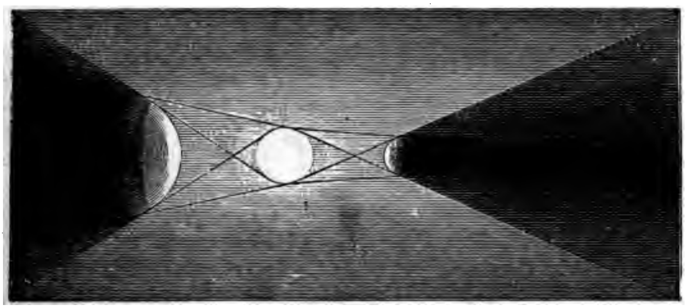

Fig. 143.—Umbra and Penumbra.

shadow is not definite in outline, but gradually shades out. The cause of this is shown in Fig. 143.

The portion directly behind the intercepting object does not receive any light from the source, and is called the *umbra.* The shaded portion on each side of this receives light from part of the source only, the part increasing as we depart from the umbra, and is called the *penumbra.*

The penumbra gives to the shadows of bodies a softness of outline which they do not receive when the source of light is very small. Moreover, as this penumbra increases in size as the distance from the body increases, this softness shows itself more conspicuously as we move the body away from its shadow.

Experiment 90.—Throw a shadow on a wall by a body close to it. Move the body away, and notice the change in distinctness of shadow.

264. **Velocity of Light.**—For a long time it was supposed that light was propagated instantaneously. Galileo took

a lantern to the top of a mountain, and had an assistant on the top of another, where there were no intervening objects. He cut off the light suddenly, and told his assistant to cut his off as soon as he missed the light from Galileo's. As he did not notice any time between the extinguishment of the two lanterns, he concluded that the light took no time to travel. He erred only in this, that the time was too small to be detected by his means of measurement.

265. **Velocity obtained from Jupiter's Moons.**—The first idea that light required *time* to travel was gained from the times of eclipses of Jupiter's satellites by the Danish astronomer Römer in 1675. To illustrate how he made the discovery, we will suppose S (Fig. 144) to represent the sun, TT′ to represent the earth's orbit around the sun, JJ′J″ a part of Jupiter's orbit, and the circles around J, the orbit of Jupiter's nearest moon. The dark spaces represent the shadow cast by Jupiter, away from the sun. The little moon plunges into this shadow at every revolution, causing an eclipse. When the earth was, we will say, at T′, Römer observed several of these eclipses, and found them to occur at uniform intervals of about 42½ hours. He then calculated *ahead* the times of a few hundred eclipses. As the earth moved down the left-hand side *of her orbit,* he found the eclipses *behind time.* In six months, the

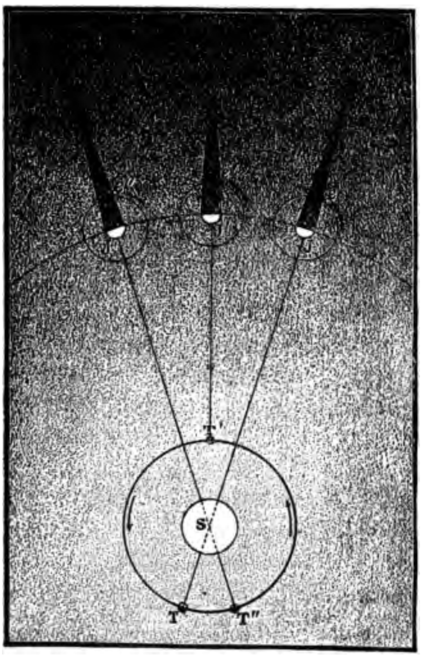

Fig. 144.—Velocity of Light by Eclipses of Jupiter's Satellites.

earth having gone nearly to T″, and Jupiter to J″, the eclipses were about 16½ minutes later than he had calculated they should be. This he rightly accounted for, after several years' trial, by supposing it took the light 16½ minutes to come straight across the earth's orbit, from T′ to T″. This distance being about 185,000,000 miles, and 16½ minutes being 990 seconds, he found the velocity of light to be 185,000,000 miles, divided by 990, or nearly 187,000 miles per second.

266. Several ingenious methods have recently been devised for measuring the velocity of light in the air, and the most accurate give 186,380 miles, or 299,940 kilometres, per second.

Exercises.—1. A board 1 foot square is held between a point of light and a wall, parallel to the wall. If 2 feet from the light and 4 feet from the wall, what is the size of the shadow?

2. A coin casts a shadow on a wall to which it is not parallel: what is the shape of the shadow?

3. A lamp 8 feet from a wall throws a shadow which is just as bright as that thrown by a candle 2 feet from the wall: compare the light of the two.

4. Light requires about 3½ years to come from the nearest star: how far away must it be?

5. Does the fact that we see the stars prove that they are in existence at the present time?

6. How long would it take light to go to the moon? how long around the earth?

II.—REFLECTION.

267. **Reflection.**—When light falls on a smooth surface which it cannot penetrate, it is turned back, *or reflected.*

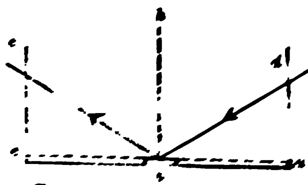

FIG. [illegible].—[illegible]

Experiment 91.—Allow sunlight to shine into a dark room through a small hole. The beam[1] will be visible by lighting up the particles of dust which are always floating in the air. It can be in this and other cases made still more evident by smoke from heavy brown paper. Let it fall perpendicularly on a mirror. The beam is turned directly back on its track. T[illegible] goes off at right angles to its [illegible].

Experiment 92.—Allow a bea[illegible]

---

[1] This is better arranged by [illegible] light into the room. A [illegible] number of interesting experiments [illegible] by Mayer and Barnard.

145) to shine through a hole in a card at *d*, to fall on a mirror at *b*, and to be reflected on another card at *e*. Make a hole at *e* at the same height above *c* that *d* is above *a*. Look through the hole at *e* and see the light reflected from *b*. Mark the exact point where the light falls at *b*. Now measure *ab* and *bc*. They will be equal. We can readily prove from this by geometry than the angle *dbh* is equal to the angle *ebh*.

268. **Incident and Reflected Rays.**—In Fig. 145, *db* is said to be the *incident* ray, and *be* the *reflected* ray; *dbh* is the *angle of incidence*, and *ebh* the *angle of reflection.*

269. **Law of Reflection.**—The general law of reflection is that *the angle of reflection is equal to the angle of incidence.*

270. **Principle of Mirrors.**—We may understand from

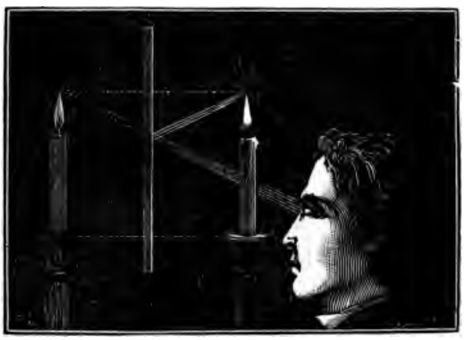

FIG. 146.—PRINCIPLE OF MIRRORS.

this and from Fig. 146 how it is that we see objects in a looking-glass. Objects are seen in the direction in which the rays of light from them enter the eye. The glass turns these rays back, making the same angle with the perpendicular that they had before, and we therefore seem to see them, back of the glass, the same distance from it that they are in reality in front of it, but inverted right and left. The image is not real: it is seen by one person only. Such images are said to be *apparent* images.

271. **Natural Objects.**—It is by the aid of reflected light that we see most natural objects. When the object is *smooth,* as a mirror, the light is reflected just as it is re-

ceived, and we see only reflected light, either as light or as images of objects. When the surface is rough, as a book, or a wall, or a landscape, the incident light is reflected in many directions, that is, *diffused*, so that it cannot make an image of objects. A small amount of light from one source, a small amount from another, and small amounts from many others, reach the eye simultaneously from any part of the rough surface, and so give us the picture of that surface. This picture may be reflected and re-reflected, and variously modified by mirrors and other appliances.

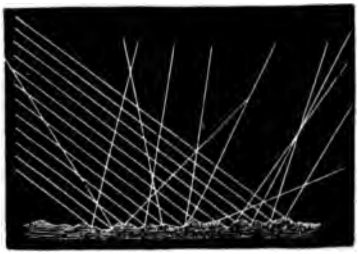

FIG. 147.—DIFFUSION OF LIGHT.

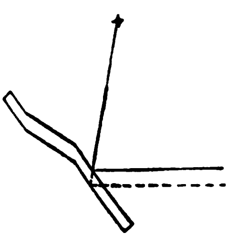

FIG. 148.—DOUBLE IMAGE.

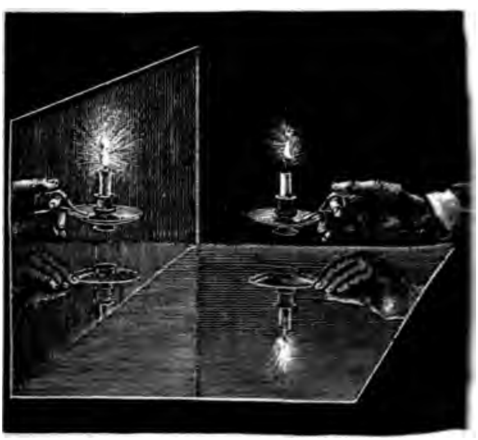

FIG. 149.—IMAGES BY TWO MIRRORS.

272. Multiple Images.—We sometimes see more than one image of an object.

Experiment 93.—Take a mirror out into the starlight, and see the reflection of a bright star or planet at an oblique angle. The star will seem to be attended by a small companion. This is due to the reflection from the front face of the glass, as shown in Fig. 148. One reflection comes to us from the silvered back of the mirror, the other, the fainter one, comes from the front face.

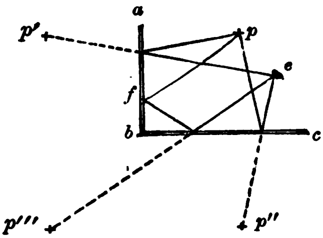

FIG. 150.—IMAGES BY TWO MIRRORS.

Experiment 93a.—If two mirrors are inclined to each other, quite a number of images may be seen. Fig. 149 shows how it may be done.

Fig. 150 gives the reason of this. If *p* is the candle, and *e* the eye of the observer, he sees one object at *p'* by direct reflection from *ab*, one at *p''* by reflection from *bc*, and one at *p'''* by reflection first from *ab* and then from *bc*.

273. The Kaleidoscope.—If two mirrors be placed at any angle with each other which is an aliquot part of 360°, there will be a definite corresponding number of images, an angle of 60° giving six views of the object, an angle of 45° giving eight views, etc. Fig. 151 is a view of a kaleidoscope, which affords a beautiful illustration of the above principle. Two long narrow pieces of looking-glass are enclosed in a pasteboard tube (cut open in the figure to show the mirrors). They are here placed at 60° with each other. The objects to be viewed are placed at *a*, and held loosely in position by the translucent cap *c*. At *b* is a cap with an eye-hole. The instrument shows a beautiful six-rayed image of the bright objects placed at *a*.

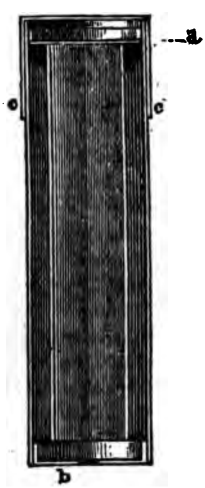

FIG. 151.—KALEIDOSCOPE.

274. Concave Mirrors.—A concave mirror is one whose face is curved *in*, or *dished*. Such mirrors reflect parallel rays to a point called the *principal focus*, and have a corresponding effect on other rays. The principal focus in a spherical mirror is half-way between the centre of the sphere, C, Fig. 152, and the surface of the

mirror. The best form, however, is not a section of a true sphere, but slightly modified.

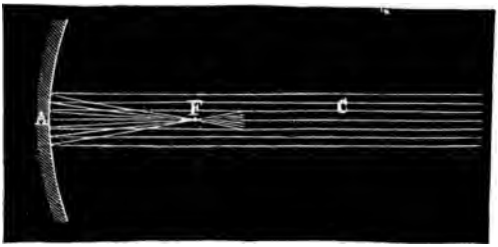

FIG. 152.—FOCUS OF CONCAVE MIRROR.

If the rays be started from the principal focus F, they will be *parallel after* reflection. Search-lights, head-lights of locomotives, etc., are made by placing a bright light near the focus of a concave mirror, and it is all reflected in nearly parallel lines to where it is wanted, rather than sent equally in all directions.

275. Conjugate Focuses.—In Fig. 153, F and C represent the same points and are in the same positions as in Fig. 152.

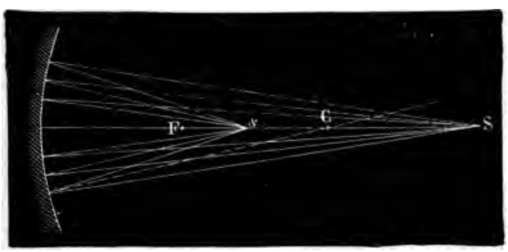

FIG. 153.—CONJUGATE FOCUSES.

As rays starting from F are reflected parallel, rays starting from *s*, making less angles with the perpendicular at the mirror, must be reflected at a less angle. (Art. 269.) They come to a point, S. The two points so situated in front of a concave mirror, that any *pencil of rays radiated from either one is reflected to the other*, are *conjugate to each*

other, and are called *conjugate focuses.* The word conjugate means united in pairs. There are thousands of points in the space in front of every concave mirror and beyond the principal focus, and each of these points has a conjugate point.

Query.—Why is there no conjugate point for a point between the principal focus and the mirror?

276. **Image by Concave Mirror.**—Suppose one thousand of the points first mentioned in the last sentence be considered as lying in the lighted candle of Fig. 154. The thousand pencils of rays radiating from them will be re-

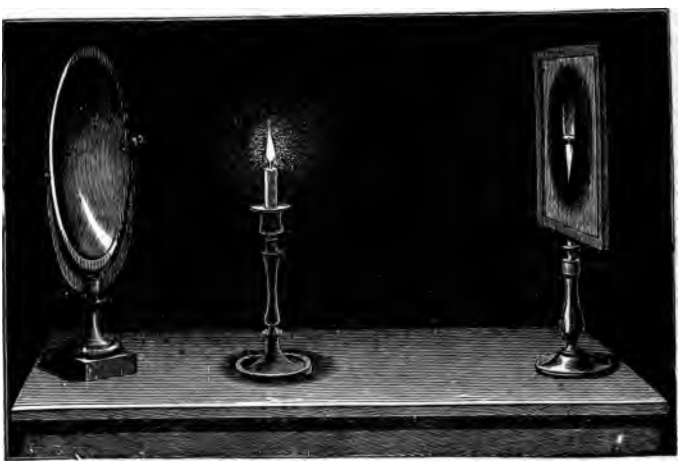

FIG. 154.—IMAGE BY CONCAVE MIRROR.

flected to the thousand conjugate points (on the screen), and will there form an inverted image of the candle. An image thus formed, so that it may be viewed *from any position*, is a *real* image. A reflection looked at *in the reflector* (or an object seen through a lens) is an *apparent* image.

The real image formed by a concave mirror is inverted, and

the relative sizes of image and object are in the direct ratio of their distances from the centre of curvature of the mirror.

Experiment 94.—If a regular concave mirror cannot be had, take a lantern reflector, a new silver spoon or watch-case, and verify the above, also the following.

277. **Apparent Image in Concave Mirror.**—**Experiment 95.** Hold any object—*e.g.*, your face—in front of a concave mirror and quite near to it. You will be convinced that

When an object is held between the principal focus and the surface of a concave mirror, an apparent image may be seen, erect and larger than the object.

278. **Convex Mirrors.**—Convex mirrors cause parallel rays to diverge from a point behind the mirror, which is the principal focus. *The image by a convex mirror is behind the mirror, apparent, erect, and smaller than the object.* A convex mirror can form no real image, because the rays do not converge after reflection, consequently there are no conjugate focuses. The bulged side of a spoon or watch-case, or a bright metal lamp, is a good convex mirror. If you have a good convex mirror, hold it in front of the whole class and verify the above statement.

279. **Diffusion of Light.**—The sun shines on the air, and the little particles of dust and vapor which it contains reflect the rays in all directions. This is the reason that sunlight gets into our rooms and under trees. This brings light to our eyes and enables us to see objects upon which the sun does not shine directly.

280. **Twilight.**—Twilight is produced by a similar cause. Even when the sun is below the horizon some of its rays are reflected to us by invisible particles in the atmosphere. As it gets farther down it shines only on the upper layers, and so the day gradually changes into night.

Exercises.—1. Shall we notice double reflection when we look perpendicularly on a mirror? Draw a figure to show that the two images will be farther apart the more obliquely we see the object reflected from the mirror.

2. Draw a diagram to show that an object seen between two parallel plane mirrors will have its image several times multiplied.

3. Draw a diagram to show that a person can see himself in a mirror half as long as himself.

4. If there were no atmosphere surrounding the earth, why would the stars look like points of light in a black sky? why would all shadows be perfectly black? Do we see any rays of light except such as enter the eye? if not, how do we see a beam of light pass through a dark room?

III.—REFRACTION.

281. **Light through Different Media.**—We have hitherto considered light as travelling only through air, and that has been considered transparent and uniform. There are, however, other substances which transmit light, and the passage of light from one transparent substance to another gives rise to a new set of phenomena which we must now study.

282. It has been stated before that the luminiferous ether exists between the molecules of transparent substances, but

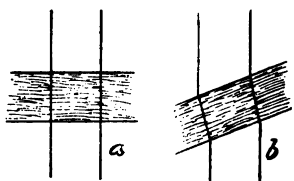

FIG. 155.—SLED-TRACKS.

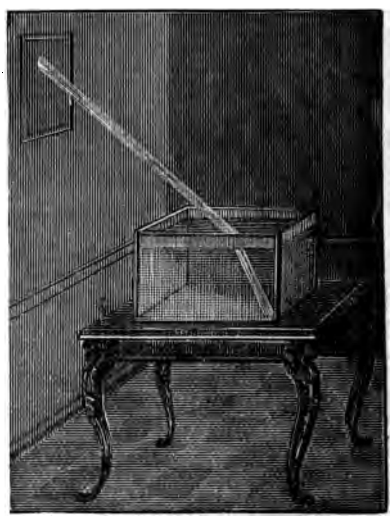

FIG. 156.—BEAM OF LIGHT REFRACTED.

that the molecules interfere, to a greater or less extent, with the vibration of the ether. A transparent substance which has much effect in stopping these vibrations is *dense*, and one which has little effect is *rare*. If a ray of light passing through a rare medium, such as air, strikes squarely against the surface of a dense medium, such as water or glass, it will simply have *its rate of speed* changed. It will go straight through the

water or glass, but *slower* than it travelled in air. It would be as though a boy coasting on an icy hill were to encounter a bank of soft snow *lying squarely* across his track, as in *a*, Fig. 155.

283. **Refraction.**—Suppose the snow-bank were *obliquely* across the track of the coaster. One runner would strike it first, and, being retarded, the sled would turn out of its course. If it came obliquely out of the snow-bank on to the icy track again, the runner first escaping from the snow would have its velocity accelerated, and again the sled's course would be changed,—*b*, Fig. 155.

Let a ray of light travelling in one medium meet the surface of a medium of different density *obliquely*, and it is deflected as the sled is, *more nearly perpendicular on entering a denser medium, but more obliquely on entering a rarer medium.* Light-rays thus bent are *refracted*, and the italics above indicate an invariable law. *Dense*, in this case, means *causing more refraction*, and *rare* means causing *less* refraction.

Experiment 96.—Admit a small beam of sunlight into a darkened room, and let it strike a *quiet* surface of water. (Fig. 156.) Instead of the vessel of water support a cubical glass paper-weight so that the beam may be seen emerging from the bottom.

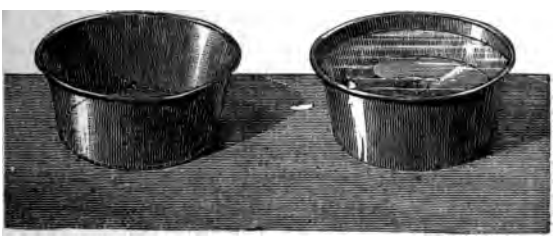

FIG. 157.—COIN MADE VISIBLE BY REFRACTION.

Experiment 97.—Place a silver dollar in the *middle* of a dish. With he dish on a table, sit ten feet away (the eye slightly higher than the ish) and have a classmate carefully fill the dish with water. The coin 'ill come into sight and appear at the farther end of the dish.

Experiment 98.—Place your eye at one end and near the surface of

the water in a long level water-trough, and estimate the *depth* of the trough throughout its whole length.

Experiment 99.—Push a stick, or an oar, obliquely into clear water, and observe the apparent break (Fig. 158).

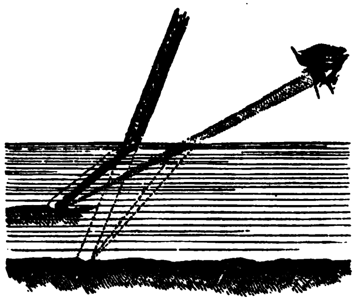

Fig. 158.—Stick "Broken" by Refraction.

Explain the last three experiments. Remember that it is the light passing *from the water into the air*, and so to the eye, that gives us the view of the object in each case.

284. **Reversal of Light-Beam.**—If a beam of light in passing from one point to another follow a given path, it would have followed the same path in going between the same points in the reverse direction. This is true whether the light passes straight in a uniform medium, or is reflected or refracted any number of times.

285. **Index of Refraction.**—An *index* is that which *indicates*. Let RI, Fig. 159, be a ray of light passing from the air into water at I. It will be refracted to *c*. Draw a circle around I, also the perpendicular line *bId*. The incident angle is measured by the line *ab*. The refracted angle is measured by the line *cd*. The amount of refraction is indicated by the relative lengths of these lines, that is, by the *ratio of ab* to *cd*, and this ratio is the *index of refraction.* For a given ray of light passing from one medium into

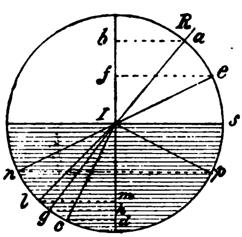

Fig. 159.—Index of Refraction.

another, as from air into water, the index of refraction is always the same. In the figure, if *ab* is 4 inches, *cd* is 3 inches, and the index of refraction is $\frac{4}{3}$. This is a *constant quantity*, no matter at what angle the ray enters the water. From air to glass the index of refraction is about $\frac{15}{10}$, and from air to diamond it is about $2\frac{1}{2}$.

286. **Total Reflection.**—Applying the principle stated in Article 284, it is evident that if light pass the other way, for instance, from water into the air, the index will be inverted, and will become $\frac{3}{4}$,—that is, *cd* will be $\frac{3}{4}$ of *ab*, *gh* will be $\frac{3}{4}$ of *ef*, and so on. Suppose *lm* equal to $\frac{3}{4}$ of the radius I*s* of the circle; then a ray going from *l* to I would be refracted to *s*,

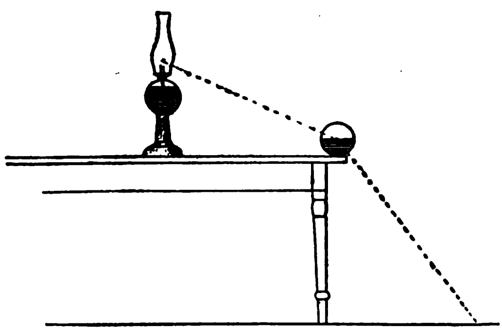

FIG. 160.—REFRACTION AND REVERSAL OF BEAM.

along the surface of the water. A ray starting from a point *n* in the water above the line *l*I, has an index greater than $\frac{3}{4}$ of the radius, and it cannot get out of the water at that place without violating its law of refraction. There are no violations of law in physics, so the ray *does not pass out* of the water at I, but is *reflected* to *p*, following the law for angle of reflection. As the light is all reflected back into the water, this is called *total* reflection. The greatest angle (*l*I*d*, Fig. 159) which a ray can make and still pass out of a denser into a rarer medium, is called the *critical* or *limiting* angle. This, of course, varies for different substances,

as the refractive index varies. Total reflection takes place only when a ray from a denser medium attempts to pass into a rarer medium at an angle greater than the limiting angle. The ray in such cases is reflected back into the denser medium.

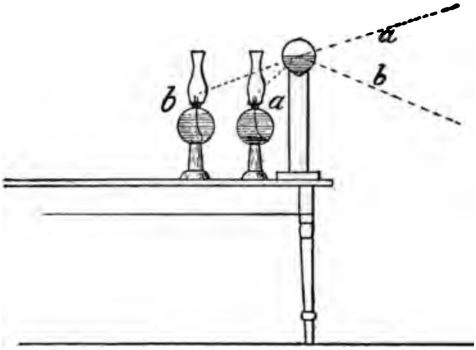

FIG. 161.—REFRACTION AND TOTAL REFLECTION.

Experiment 100.—Prove all the statements of the last three articles by means of a round bottle just half full of water and tightly corked. The larger and clearer the bottle the better. Support the bottle on the edge of a table, as shown in Fig. 160. Place a lamp on the table, and when the water has become quiet observe the spot of light on the floor, in the shadow of the table. This is the refracted beam from the lamp. Mark it with any small bright object. Now remove the lamp from the table, illuminate the bright object, place the eye just where the lamp was, and look at the bottle. The spot will appear. (Art. 284.) To prove Article 285, replace the lamp, move it back and forth on the table, and measure the lines *ab*, *cd*, etc. (Fig. 159), with a foot-rule.

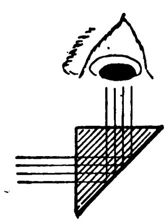

FIG. 162.—TOTAL REFLECTION IN PRISM.

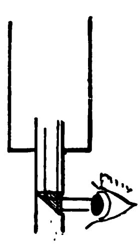

FIG. 163.—PRISM IN EYE-PIECE.

To prove Article 286, support the bottle *above* the level of the lamp-flame (a foot is sufficient). Place the lamp nearly *under* the bottle, and notice the spot of refracted light on the ceiling just beyond the shadow of part of the bottle. Slip the lamp *back* on the table. Suddenly the bright spot will leave the *ceiling* and appear on the floor. Place the eye there and look at the

bottle of water. The lamp-flame will be seen. Sunlight may be used all through these experiments, catching it on a looking-glass laid on the window-sill, when it is to be directed upward. In Fig. 161, *a* is the beam from *a*, and *b* from *b*.

Experiment 101.—A triangular glass prism, held as shown in Fig. 162, shows beautiful reflections of landscape when used near a window.

Telescopes and other optical instruments sometimes have prisms in the eye-piece, so that the observer may look at objects directly overhead without bending his neck backward very uncomfortably. (Fig. 163.)

FIG. 164.—REFRACTION BY TRIANGULAR PRISM.

287. **Refraction by a Prism.**—**Experiment 102.**—Look at a lamp with a prism, as in Fig. 164. See that one side of the prism is parallel with the table. The lamp-flame will appear *higher*, because the light ray is refracted downward, as shown. (The colors will be explained hereafter.)

288. If two prisms be held base to base as shown in Fig. 165, the parallel beams *a* and *c* will be refracted to the point *f*. If the prisms

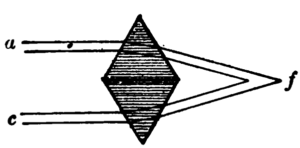

FIG. 165.—PRISMS CONVERGING LIGHT.

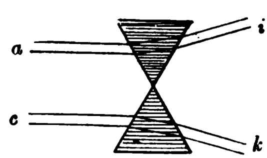

FIG. 166.—PRISMS DIVERGING LIGHT.

be placed point to point, the rays will not approach each other after refraction, but will take the directions *i* and *k*, Fig. 166.

289. Lenses.—If Fig. 165 be rounded on the sides, it would present an appearance something like *a*, Fig. 167,

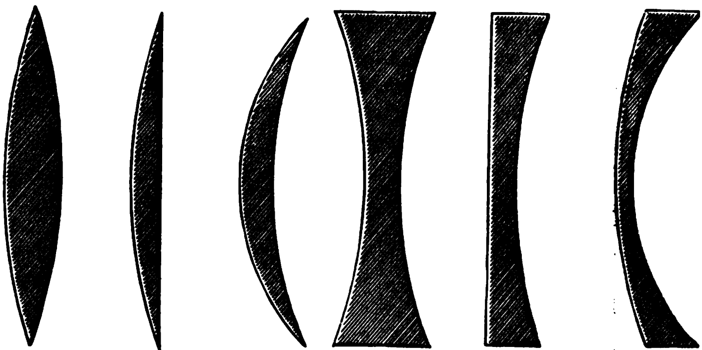

Fig. 167.—Lenses.

and Fig. 166, rounded, would be something like *d*. These are types of the two classes of *lenses*, *convex* and *concave;* and the effect of each class on parallel beams of light is shown in Figs. 165 and 166. A lens, then, is a transparent body with polished curved surfaces. In Fig. 167 are shown

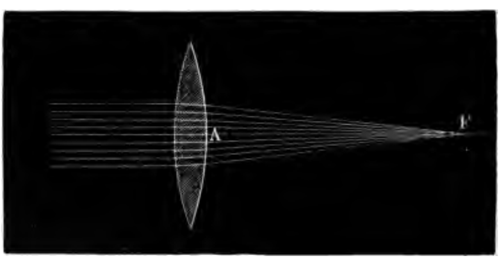

Fig. 168.—Principal Focus.

six forms of lenses, and there are many others. The first three are convex, *thicker* towards the middle; the others are concave, *thinner* towards the middle. Any straight line *through* the centre of a lens is an *axis*, as AB, Fig. 169.

290. **Effect of Lenses.**—A convex lens refracts rays of light *towards* the axis; a concave lens refracts rays *from* the axis.

The glasses of ordinary spectacles are lenses, generally convex. If they are convex they will concentrate the light from the sun or from a lamp nearly to a point.

291. **Focus of Convex Lens.**—A convex lens brings *parallel* rays of light to a point called the *principal focus.* The *focal length* of a lens is the distance of the principal focus from the centre of the lens. (AF, Fig. 168.) The sharper the curvature of a lens (the smaller the lens) the *less* its focal length.

A pencil of rays issuing from *any point* (as B, Fig. 169) *beyond the principal focus* of a lens, will converge to some point (as A) on the other side of the lens. These

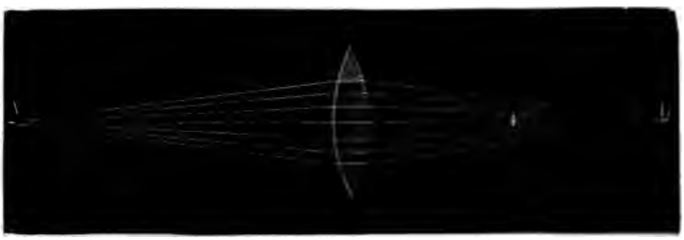

FIG. 169.—CONJUGATE FOCUSES.

two points are conjugate to each other (Art. 275), and are called *conjugate focuses.* The straight line joining any two conjugate focuses of a lens passes through the centre of the lens.

292. **Image by Convex Lens.**—By the last article, *every point beyond the principal focus of a convex lens has a conjugate focus on the other side of the lens* (also beyond the principal focus). An illuminated object (AB, Fig. 170), placed beyond the focus of the lens O, is made up of thousands of *points.* All rays of light from a given point, A, *passing through any part of the lens,* are brought to a point at A's conjugate focus, *a.* All rays from B are concentrated at *b,* and so for every other point of the object AB.

The result is the image *ab*. This is inverted, because the lines joining any two conjugate focuses pass through the centre of the lens. They therefore all *cross* at the centre.

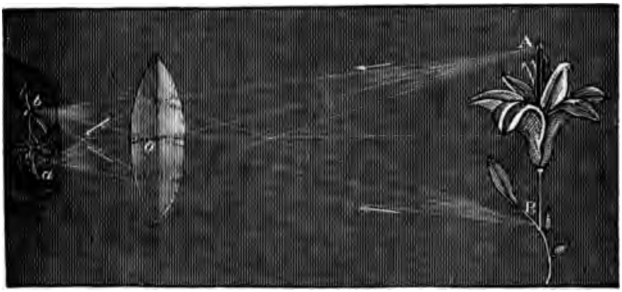

FIG. 170.—IMAGE BY CONVEX LENS. (SMALLER THAN OBJECT.)

Experiment 103.—Hold a lens (magnifying-glass, and as large as possible) near a white wall or screen opposite a bright window, all other windows in the room being darkened. Move the lens back and forth till a perfect image of the window shows on the wall. With a

FIG. 171.—IMAGE BY CONVEX LENS. (LARGER THAN OBJECT.)

card, gradually cover up the lens. The *brightness* of the image gradually fades, the *form* remains while any light comes through. This shows that light comes to the proper conjugate points no matter what part of the lens it passes through.

Experiment 104.—Repeat the last experiment at night, throwing the image of the lamp-flame or shade on the wall. The lamp should be four or five times the focal length of the lens from the wall. When a distinct image is formed with the lens held near the wall, notice its distance from the wall. Now move it up until it is that distance from the lamp-flame. A larger image will appear on the wall.

293. Relative Size of Image and Object.—The last experiment establishes the important principle that *the relative sizes* (linear dimensions) *of image and object are in the direct ratio of their distances from the centre of the lens.* This is made clear by comparing Figs. 170 and 171. The farther

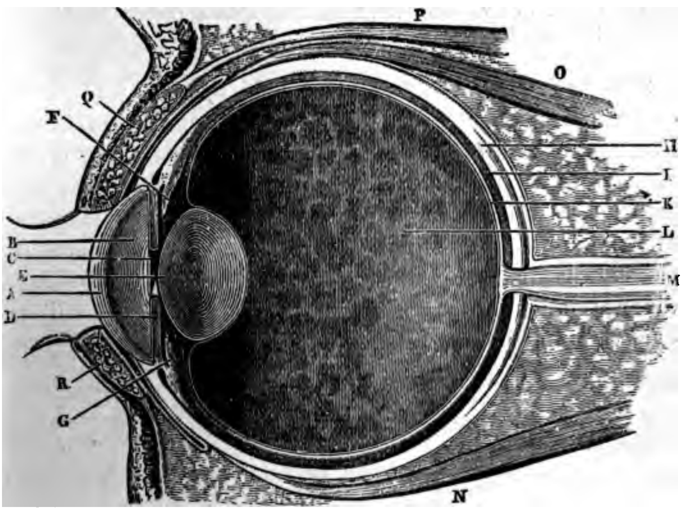

FIG. 172.—THE HUMAN EYE.
A, cornea; B, aqueous humor; C, pupil; D, iris; E, crystalline lens; H, sclerotic coat; I, choroid coat; K, retina; L, vitreous humor; M, optic nerve; N, O, P, muscles.

the straight lines through the centre of the lens pass, the farther they diverge.

294. The Eye.—To understand the use of a convex lens as a magnifying-glass, or as an eye-piece of a telescope or microscope, it is necessary first to understand the structure and use of our own eyes. The human eye is a ball, rather

more than an inch in diameter. Its various parts are named in the figure. Its optical properties will be described here, and the rest will be found in Physiology.

The crystalline lens (E), assisted somewhat by the cornea (A), produces an inverted image on the retina (K). The retina consists of fibres from the optic nerve (M). This nerve conveys the impressions made upon the retina to the brain, and gives us our knowledge of the objects which we look at.

Experiment 105.—Procure an eye of an ox or other animal, freeze it, and cut it in two from front to back with a razor. Notice the various parts described above.

295. **As in the case of the lens** held before a screen, the object and image are in conjugate focuses of the crystalline lens. The *focal length* of this lens, however, is *very nearly the same* as its distance from the screen (retina). As only *parallel* rays are brought to a point at the principal focus of a lens, the eye cannot form an image, and, therefore, cannot see distinctly objects so near to it that the rays diverge much on entering the pupil (C). This will be evident from the diagram. (Fig. 173.)

FIG. 173.—DISTANCE OF DISTINCT VISION.

The object *o* is at such a distance (about a foot) that all the rays from *any one point* of that object which can enter the pupil (about $\frac{1}{8}$ of an inch in diameter) are within about one degree of parallel. The crystalline lens can converge these to a point on the retina. If the object were moved up towards the eye, as in Fig. 174, the rays from any point would be so much divergent on reaching the crystalline lens, that it could not converge them to a point on the retina. Try this by moving the page of this book up

towards the eye while reading. Within a certain limit the letters will be indistinct.

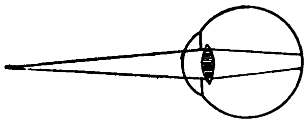

FIG. 174.—TOO CLOSE FOR DISTINCT VISION.

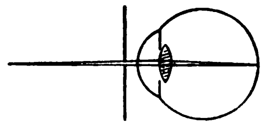

FIG. 175.—DISTINCT VISION THROUGH PIN-HOLE.

Experiment 106.—Punch a pin-hole in a sheet of paper, put it close to the eye, and bring the eye to within two or three inches of the page. Have sunlight on the page. Vision will be distinct. Explain this. (See Fig. 175.)

296. **Adaptation of the Crystalline Lens.**—The crystalline lens changes its curvature to view objects at different distances. For close objects it is more convex, and for distant objects it is stretched and rendered less convex. (Art. 291.) This is accomplished by the muscles. (F, Fig. 172.) It is done without consciousness on our part. The pain which results from trying to see an object (printing, for instance) too close to the eye, is due to the effort of the crystalline lens to adapt itself to the short distance.

297. **Use of Spectacles.**—When the crystalline lens is naturally too much convex (*near-sighted* persons) or too little convex (old and *long-sighted* persons), the eye becomes painful and diseased by its own efforts to adapt itself to what is required of it. Persons affected in either way should wear glasses to relieve the eye of the strain.

Which should wear convex, and which concave lenses?

298. **The Camera.**—The camera used by photographers is a box entirely dark inside when closed. It has a convex lens in front and a screen of ground glass behind, on which the lens throws an inverted image of objects in front of it. When this image is made clear by careful "focusing," the

lens is covered, the sensitive plate takes the place of the ground glass, the lens is uncovered again for a few seconds, and the picture is impressed upon the plate. For portraits the photographer uses a larger lens. For landscapes, where it is desirable to focus on the plate objects at various distances, he secures "depth of focus" by covering his lens, except a small part of the middle, by a "stop." (See Experiment 106.)

299. **The Projecting Lantern.**—In the projecting lantern, magic lantern, or stereopticon (Fig. 176), a picture on glass is placed upside down, and transposed right and left, in a suitable holder at C, and powerfully illuminated by concentrating on it with a large lens, B (the "condenser"), the rays from some bright source of light. The projecting lens, or "objective," D, a combination of double-convex lenses, is placed in front of this picture at a distance of a few inches, and forms an image on the screen many feet away. The size of the image on the screen depends upon its distance from the lantern; but great size is not often desirable, as the brightness of the image decreases with the size, following the law of intensity. (Art. 261.) The light for a projecting lantern is mostly obtained from a lime cylinder, A, heated in the oxyhydrogen blowpipe. Electric light, sun-light, or lamp-light may be substituted. Sunlight is specially desirable for microscopic objects, where great enlargement of the image is obtained.

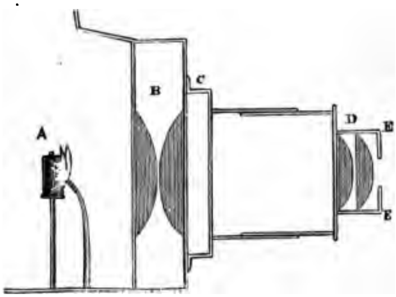

FIG. 176.—PROJECTING LANTERN.

300. **The Magnifying-Glass.**—The magnifying-glass is a convex lens, or sometimes two or three convex lenses close *together* and used as one. It will form a real inverted

image of an object, as explained in Article 292; but that is not its use as a magnifier. It is ordinarily a small lens of short focal length. Its application may be understood from

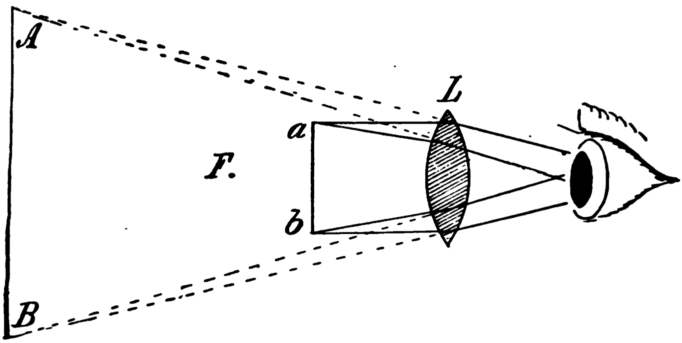

FIG. 177.—PRINCIPLE OF THE MAGNIFYING-GLASS.

the diagram (Fig. 177). Suppose F to represent the principal focus of the lens L. The lens is placed within its focal length of the object to be viewed, *ab*. The rays divergent from any point, *a*, are rendered less divergent by the lens,

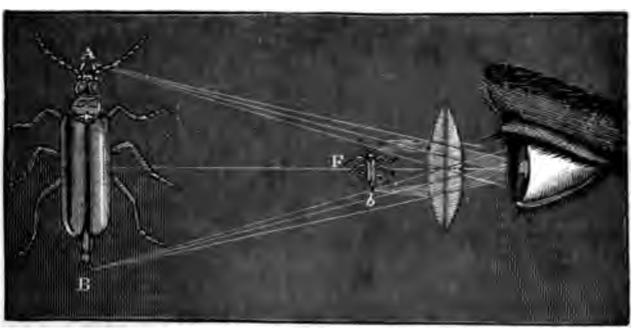

FIG. 178.—THE MAGNIFYING-GLASS.

and are refracted towards the central axis. So with the rays from any other point, *b*. The eye placed near where these rays, or rather *pencils*, cross, sees the rays from *a* as though

they came from A, and those from *b* as though they came from B.

AB is called a *virtual* or *apparent* image. It is always erect and larger than the object.

301. **The Concave Lens,** when held between the eye and an object, forms a virtual image between the object and the lens, which is erect and smaller than the object.

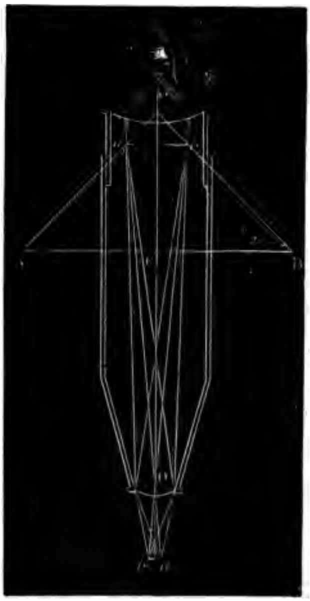

FIG. 179.—THE MICROSCOPE.

302. **The Microscope.**—The microscope consists of two convex lenses, one of very short focus placed near the object. This is the *objective.* It forms a real inverted image of the object near the top of the tube. This image, on account of its greater distance from the objective, is many times larger than the object. It is further magnified, however, by the *eye-piece,* the second lens mentioned above. It is in effect a magnifying-glass. Fig. 179 shows the arrangements of the parts of a microscope.

A good combination of lenses in a microscope will magnify 1000, or even 2000, diameters.

303. **The Telescope.**—A telescope is the same in principle as the microscope, except that the objective is made of long focus instead of short focus. The telescope is for viewing objects far away. The objective forms an image of the distant object, near its principal focus. The *size* of this image depends upon its *distance from the objective.* The sun or moon makes an image one inch in diameter when the

focus is ten feet from the lens. This image is viewed through an eye-piece which easily magnifies it from 100 to 500 diameters or more. With the same eye-piece, a telescope of 50 feet focal length will give an image 10 times as large as a telescope of 5 feet focal length.

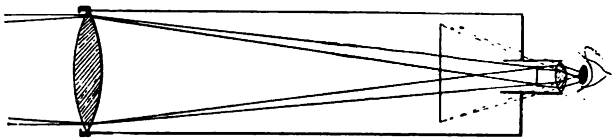

FIG. 180.—PRINCIPLE OF THE TELESCOPE.

In the telescope and all optical instruments, lenses of long focus must be made large, else they transmit so small an amount of light that the large image will be too dim to be easily seen. Great focal length in a lens is not hard to attain; but great focal length, great size, and perfect "definition" are so hard to attain, that large telescopes of this kind are very expensive. The objective of the great Lick telescope, Mount Hamilton, California, is 36 inches in diameter, 57 feet focal length, and (lens only) cost about $50,000.

304. **Reflecting Telescopes.**—The largest telescopes use a concave mirror to *reflect* the light from the heavenly bodies

FIG. 181.—PRINCIPLE OF THE REFLECTING TELESCOPE.

to a focus, where an image is produced. A small mirror, or total reflecting prism, is placed near the focus to reflect the light to the eye-piece which is placed in the side of the tube. (Fig. 181.) This form of reflector was invented by Sir Isaac Newton. There are other forms, the difference

consisting in the device for getting the light to the eye-piece.

305. **The Spy-Glass.**—In both forms of astronomical telescopes the image is inverted. To the astronomer this makes no difference. In ordinary spy-glasses, surveyors' instruments, and other telescopes for viewing things on the surface of the earth, it is desirable to have the image erect. This is accomplished by inserting two more lenses in the eye-piece: one to cross the rays from the image, and another to form a second image for the eye-lens to view.

306. **Opera-Glasses.**—The first telescope ever made—Galileo's—was a combination of a convex objective with a con-

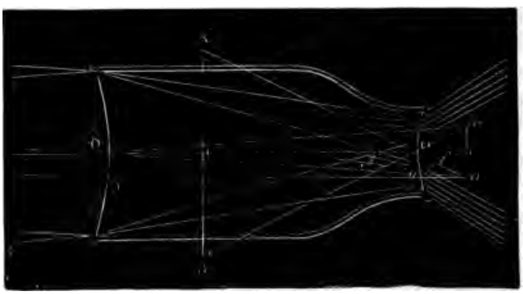

FIG. 182.—PRINCIPLE OF THE OPERA-GLASS.

cave eye-piece. The latter was placed so as to intercept the rays before they reached the focus, so that no image was formed by the objective. An apparent image was formed by the eye-piece, which was erect. This telescope has a large field of view, but small magnifying power, and is used in opera-glasses. Each tube is such a telescope.

307. **To Measure the Magnifying Power of a Telescope.**—**Experiment 107.**—Place a spy-glass, or small telescope of any kind, a few rods from a well-illuminated brick wall. Have the glass firmly secured to a stand or tree. Look through the glass with one eye, and when a good image of a brick is obtained, open the other eye and see how many bricks in the wall are covered by the magnified brick. Do not omit to count in the thickness of the mortar. Notice how *much more dim* the magnified image is than the real brick.

308. **The Stereoscope.**—The stereoscope may be understood from Fig. 183. The two views *a* and *b* of an object have been photographed with a camera having two lenses about four inches apart, so that one is a view of the right-hand side of the object to a slight extent, the other of the left-hand side. The lenses of the stereoscope are, in effect, a double-convex lens cut in two, and the halves placed point to point. The light from *a* and *b* is refracted, as shown, so that both *appear* to come from *c*, and the optic nerve effects a combination of the right-hand and left-hand views, and gives the appearance of *depth* or *solidity* to the picture. A good stereoscopic view thus "stands out" remarkably.

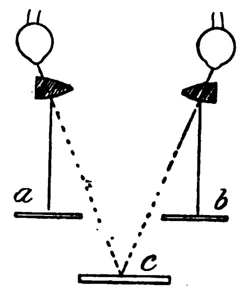

FIG. 183.—PRINCIPLE OF THE STEREOSCOPE.

IV.—DISPERSION.

309. **Color in Refracted Light.**—In Experiment 102, the flame was seen not only out of its real position, but surrounded by a zone of brilliant colors. If we look at anything in ordinary light through a prism, we see similar colors. To make the cause of these colors clearer, we will vary the experiment as follows:

Experiment 108.—Into a darkened room admit a beam of sunlight through a horizontal slit rather shorter than the prism and one-fourth of an inch wide. Cut the slit in a piece of cardboard, and cover the rest of the window as well as possible. Catch the beam on a prism, as shown in Fig. 184. A beautiful band of colors will appear on the wall or ceiling. If you have a triangular glass bottle or trough filled with carbon bisulphide, the band will be longer.

310. **The Spectrum.**—The light is *dispersed* on passing through the prism,—that is, separated into all the colors which it contains. The band of colors so produced is a *spectrum*. If the light is from the sun, it is the *solar* spectrum. By examining the colors of the solar spectrum, or

of a spectrum made by any ordinary light, we find the following colors in order, each one shading into the next: violet, indigo, blue, green, yellow, orange, red,—the violet being refracted *most*, and the red *least*.

311. **Cause of the Spectrum.**—In Article 257 we learned that the *longest* light-waves are those producing the sensation of *red*, that the *shortest* are those producing the sensation of *violet*, and that *all* the vibrations in a beam of

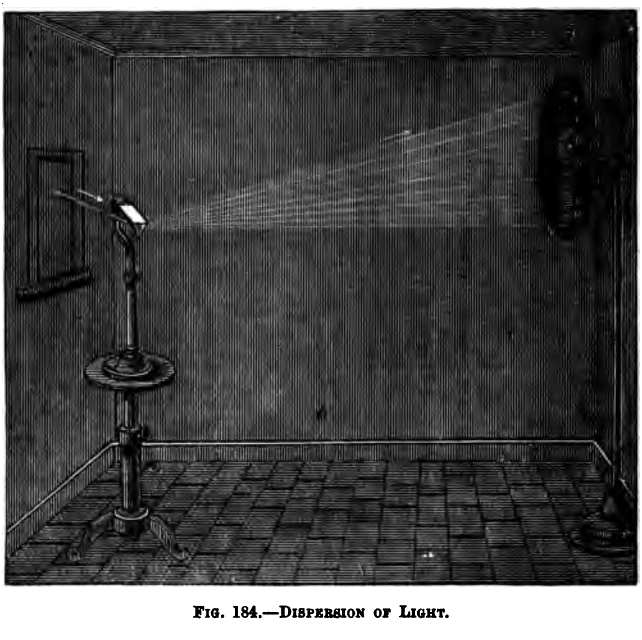

FIG. 184.—DISPERSION OF LIGHT.

ordinary light produce on our eye, or brain, the sensation of white. White light, then, consists of a large number of waves travelling together, varying in length between the extremes of red and violet. When they strike the glass obliquely, they are all retarded and refracted; but the waves of violet light being the shortest are retarded most by the glass, and, consequently, are refracted most; while

the red rays being the longest are, by the same reasoning, refracted least. The intermediate wave-lengths are refracted to intermediate positions, and we have the spectrum.

312. It is because there is every possible wave-length between the extremes of red and violet that there is no definite line between each of the two adjacent colors of the spectrum. A certain rate of vibration produces a definite impression of green, a certain other rate produces a definite impression of blue. Between these there are many wave-lengths, and the medium waves are neither green nor blue.

313. **Invisible Spectrum.**—Energy is radiated from the sun, and in a much less degree from other sources of light and heat, in ether-waves, which vary in length through a much wider range than that in the visible spectrum, or in what we call light. The vibrations which give us the sensation of heat, those which make the impression on a photographer's plate, those which produce the wonderful chemical changes in the growth of healthy plants, and, probably, those which convey electrical energy through space, are waves of the same ether, differing only in length and in rapidity of vibration from light-waves. It is because the vibrations of certain rapidity are capable of affecting the optic nerve that they constitute *light*. The slower vibrations affect our nerves of feeling, and are *heat*. The more rapid vibrations produce the chemical changes of plant growth and of photography, and they are called the *actinic* radiations of the sun. When any of these vibrations, or all together, are intercepted by a prism, they are refracted and dispersed as light-waves are,—the longer and slower *less*, the shorter and more rapid *more*, than light. Below R (Fig. 184) is a heat

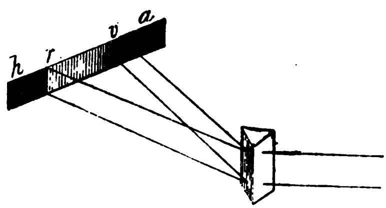

FIG. 185.—INVISIBLE SPECTRUM.

spectrum nearly as long as the visible spectrum and much warmer, and above V is the actinic spectrum, capable of producing a photograph in less time than any part of the visible spectrum will do it. A photographic print on glass may be taken instantly in space utterly dark to the eye, as the hand may be burned by contact with a black stove. In Fig. 185, the light spectrum extends from *r* to *v*, the *heat* is at *h*, and the greatest chemical energy at *a*.

314. **Recomposition of Light.**—As the light which produces a spectrum is white to the eye before being dispersed,

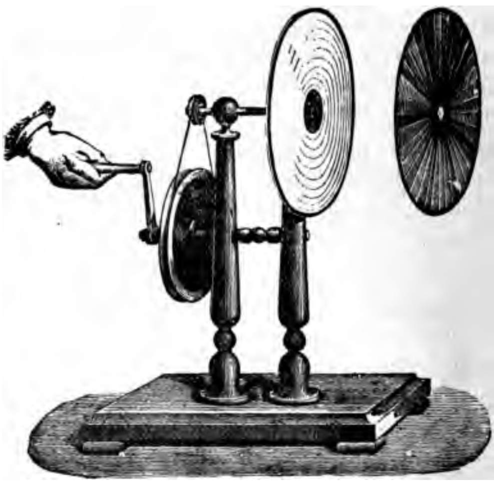

FIG. 186.—COLOR-DISK.

so the colors of the spectrum may be recombined and produce the impression of white light. This may be done in various ways.

Experiment 109.—Catch the spectrum, Fig. 184, on a mirror, and throw it back to the wall under the window, or to the ceiling or floor. Having mounted the mirror on a horizontal axis (a wire run through the two sides of the frame, with the end bent to form a crank), turn it around once a second. The band of light thrown around the room will be white. The eye retains all impressions of light for a fraction of a second. When we look at any spot as the light is whirled past, the

impression of any one color remains till *all* have been made, and the optic nerve sends them to the brain together. If you can *follow* the rotating image of the spectrum with the eye, it will appear as a spectrum.

315. The colors may be recombined by a lens, by a prism placed in the spectrum close to the dispersing prism and the other side up, or by the color-disk, shown in Fig. 186. The colors of the spectrum are painted on the disk, and when it is rapidly rotated they blend to form white.

316. **The Spectroscope,** shown in Fig. 187, is an instrument used in observing the colors with which certain substances burn, and thus determining what they are composed of.

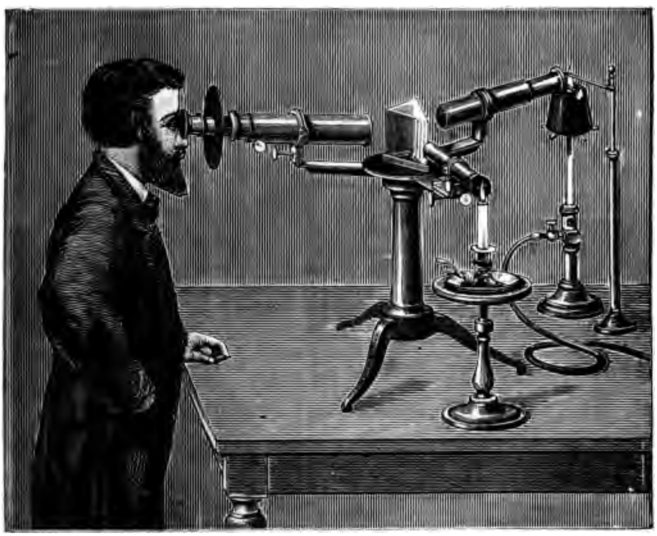

FIG. 187.—THE SPECTROSCOPE.

The substance to be examined is burned in the lamp at the right. This illuminates a narrow slit, and the lenses in the tubes produce an image of this slit near the observer's eye. As the light from the slit passes through the prism before the image is formed, it is *dispersed*, and the observer on looking through the eye-piece sees a *spectrum*. The third

tube contains an illuminated scale of equal parts for determining the position of lines in the spectrum.

317. **Different Kinds of Spectra.**—Spectra are of three kinds:

1st. *Continuous spectra*, made by light from *glowing solid or liquid substances.* (See also Art. 322.)

2d. *Bright-line spectra*, made by light from *burning or glowing vapors.*

3d. *Dark-line spectra*, made by light of the *first kind*, *after passing through light of the second kind.*

318. **Continuous Spectrum.**—Any ordinary artificial light gives a spectrum of the first kind. The flames of lamps are light because of particles of glowing carbon in them. A continuous spectrum is one in which the colors shade into one another from end to end without a break. Fig. 188 represents a band of light from a white-hot lime, supposed to have passed through a slit and a lens, not shown in the figure, dispersed by the prism and making a continuous band of colors, from red, *r*, to violet, *v*. (Colors shown in top line of frontispiece.)

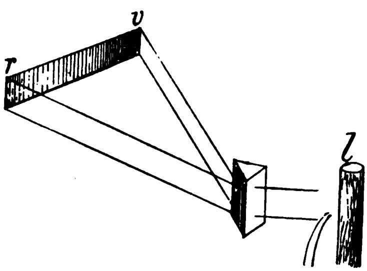

FIG. 188.—CONTINUOUS SPECTRUM.

319. **Bright-Line Spectrum.**—When a substance is vaporized and burned at a high temperature, the light, instead of consisting of *all* wave-lengths, contains very few, and, these being widely separated by the spectroscope, we can see distinctly what they are. Two substances may give lights very much alike to the naked eye, but the mixtures of colors producing them may be very different. Lithium and strontium burn with similar red flames, yet when viewed by a spectroscope the lithium light is found to be composed of two colors only, and the strontium of many.

(See frontispiece.) Thus all substances which may be burned, or otherwise highly heated as true vapors, give bright-line spectra, and they are *all different*. This gives a means of detecting some substances. The spectra of those most easily burned in this way are shown in the frontispiece.

320. **Dark-Line Spectrum.**—When white light passes through a burning or glowing gas, the light of the gas quenches a part or all of its own color in the white light, and the spectrum of the white light then shows dark bands in the place of the light which has been thus absorbed. In

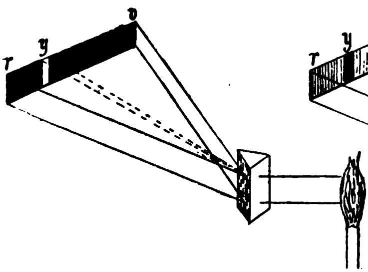

FIG. 189.—SPECTRUM OF SODIUM VAPOR.

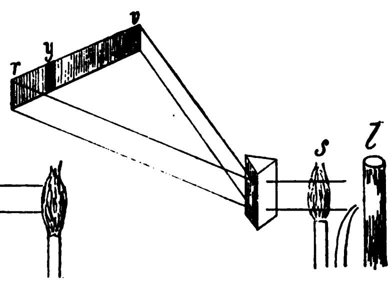

FIG. 190.—DARK-LINE SPECTRUM.

Fig. 189 the source of light is a gas-flame burning sodium vapor. There is a single bright yellow image of the slit on the wall, the rest of the place for the visible spectrum being dark. In Fig. 190, the lime-light, *l*, is placed behind the burning sodium, and on the wall is the spectrum of the lime-light from *r* to *v*, except that the yellow is cut out by a *dark* image of the slit, just where the *bright* image is in Fig. 189.

Thus the dark-line spectrum also gives us a means of detecting substances as glowing vapors, when they have a glowing solid or liquid behind them, for the dark bands correspond in position with the bright bands which those same vapors alone would give. The three kinds of spectra also give us the means of determining what condition some dis-

tant bodies are in. The sun, for instance, gives a dark-line spectrum (see frontispiece), showing that it is composed of a white-hot solid or liquid surface, surrounded by an atmosphere of glowing gas. The position of the bands tells us what substances are in the atmosphere of the sun, but nothing as to what composes his surface or nucleus.

321. In Experiment 108, the dark lines of the solar spectrum were covered up by the width of the slit, the colors overlapping. Each bright band or dark band in the spectrum is an *image of the slit.* The stars give spectra like the sun's.

322. **Convergence of Spectra.**—Any substance which burns with a *flame* is a gas, and, consequently, gives a bright-line spectrum. If a burning gas cool down, the bright lines approach one another by broadening, till finally they meet and form a continuous spectrum. The burning substance has then reached the liquid or solid condition. If a gas be burned under great pressure it gives a continuous spectrum. The pressure interferes with the perfectly free motion of the molecules, just as cohesion does in the solid or liquid state, and free motion of the molecules is essential to the production of the differing wave-lengths which give the bright bands.

323. **The Rainbow.**—The rainbow is a spectrum. Raindrops are the prisms. Whenever a ray of light enters one of these drops there is refraction, and wherever there is refraction of white light there is dispersion.

The red is on the outside of the arc, and the violet on the inside. When there is a fainter secondary bow the order of colors is reversed. The radius of the arc is about 41°,[1] and its centre is always exactly opposite the sun.

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[1] A little less than half the distance from the horizon to the zenith.

When the sun is just setting, how much of a circle is seen? how *near to the* horizon must the sun be to make a bow?

The path of the rays through a drop is seen in Fig. 191. From S the rays come, are refracted at I, reflected at A, and

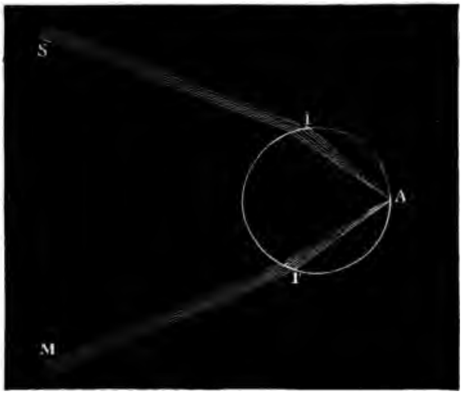

FIG. 191.—PATH OF RAYS TO FORM PRIMARY BOW.

again refracted at I′, and pass out dispersed towards M. The lines SI and I′M make an angle of about 41° with each other. Hence a person standing so that he would receive these rays, I′M, would have them colored. But the air is full of drops. Those in such a position at any instant as to send the ray to the observer would always be 41° (for the red 42½°, and for the violet 40½°) distant from the point opposite the sun, and hence would lie in an arc of a circle.

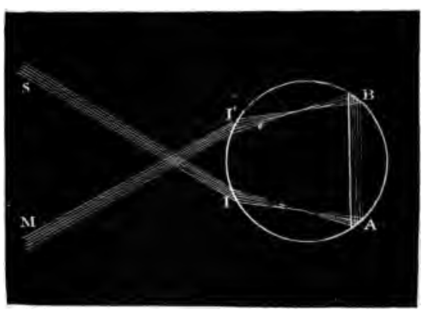

FIG. 192.—PATH OF RAYS TO FORM SECONDARY BOW.

Other rays which enter the drop are also refracted, but only those which pass as in the figure are kept together so as to make an impression. The remainder are scattered.

The secondary bow is produced by two refractions and two reflections, as in Fig. 192.

324. Fig. 198 shows the formation of both bows; *a* and *a'* indicate the position of drops from which violet rays reach the eye, and *b* and *b'* the position of drops from which red rays reach the eye. Intermediate

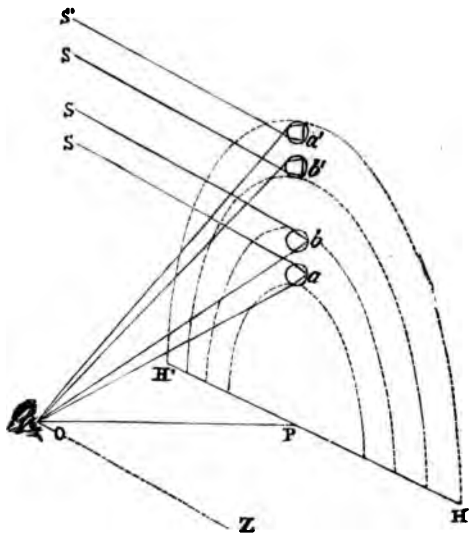

FIG. 193.—FORMATION OF PRIMARY AND SECONDARY BOWS.

drops send the other colors to the observer. Of course every ray issuing from each drop is dispersed into all the colors of the bow, but only one ray from each drop reaches the observer. For instance, the violet and all other rays from *b* which are refracted more than red pass *above* the observer's eye; similarly all rays from *a* which are refracted less than violet pass *below* the eye. No two persons see exactly the same bow.

325. Colors of Opaque Objects.—It has been said that the light which opaque objects diffuse is that by which they are seen. But the light which such objects diffuse is light which is reflected after having slightly entered their surfaces. During the passage of the light twice through the very shallow layer which it thus traverses, it frequently has some

of its rays absorbed, or quenched, and the remainder of the light is not white but colored. For instance, if a surface quench red, it will appear to the eye some shade of green. If it quench green, it will appear some shade of red. This effect may be very conclusively shown with the color-disk. (Art. 315.) Cover up all the green sectors of such a disk by pasting pieces of black muslin over them. On rotating the disk it will appear *purplish red!* The effect is as good if a few inches only of the green sectors are covered. The patches may then be permanent, and there will be a red zone in the disk when rotated.

326. **Colors of Transparent Objects.**—Transparent objects are seen by light which they transmit. Some things partially transparent are of one color by reflected light and of another color by transmitted light. A *thin* gold leaf held between the eye and the sun is *green.*

327. **Colors of Objects in Colored Light.**—Natural objects differ from one another in regard to the particular rays which they quench or transmit. An opaque substance which reflects *all* the light of the sun, or of a lamp, is *white.* One which reflects *none* is black. A white object seen in light of any color is the color of the light, because it can reflect any color. Not so, however, with colored objects. They can reflect no color perfectly but their own.

Experiment 110.—Carry into the "dark room" of your photographic friend a number of pieces of bright ribbon or paper. The red and yellow pieces will look nearly natural. All other colors will probably appear black. Your face and hands, and the photographer's white plate, will appear *red.* If you have no photographic friend at hand, go into any dark room with your ribbon, and light the room with an alcohol lamp whose wick is well covered with salt. The effects will be all yellow or black. Contemplate your complexion!

328. **The Color-Sense.**—The nerve-fibres in the retina of the eye differ in their capacity of taking up light-waves. Those which respond to the slower vibrations send to the brain the impression of red, and those which respond to the more rapid give us the impression of violet, while intervening color-sensations are produced through the action, in

whole or in part, of other nerve-fibres. When all the nerve-fibres are brought into action equally and at the same time, we have the sensation of white.

329. **Color-Blindness.**—Some persons are unable to distinguish certain colors. This is probably due to a defect in the optic nerve, which renders some of the nerve-fibres inactive. Blindness to *red* is the most common form of this defect or disease. A person so afflicted sees no difference between red and gray. His vision may be keen and his color-sense may be good for green, blue, and violet. Some persons are blind to the greens and blues only, and occasionally a person is found with no idea of difference between any bright colors.

The writer once dined with an intelligent gentleman who offered him stewed tomatoes for apple-sauce, and he has a very pleasant recollection of a student in chemistry who could *see* no difference between Paris green and Prussian blue!

330. A person cannot describe his color-sense to another. It is probable, though not certain, that all persons with normal vision see the same colors alike. The test of absence of color-blindness consists in the ability to *match* bright ribbons or yarns of all ordinary colors. This is required of engineers and pilots, who must know signals by color.

331. **Primary Colors.**—Though we see all possible shades of color between the extreme red and the extreme violet, it is believed that the nerve-fibres of the eye are sensitive mainly to the three colors, red, green, and violet, and that the sense of other colors is produced by a blending in the brain of these. They are therefore called the *primary colors.* The colors between red and green are produced by combining red and green, the hue being orange, yellow, or greenish yellow, depending on the preponderance of one or the other of the primary colors. So the colors between green and violet are produced by blending the colors between the two. When violet and red are blended it produces purple. Neither of the three primary colors can be *produced by* the blending of others.

There are many ways in which this may be shown. The following is good. A narrow beam of light (Fig. 194) passes through the prism, which produces a spectrum at *rv*. Here are placed four small mirrors: one in the red, one in the violet, and two—one above the other—in the green. These are arranged as shown in the figure, so that red and green are reflected to the same point, *y*, on a screen, where a yellow spot will appear. The other mirror in green is so turned as to reflect to *b*, and the violet from *v* is reflected to the same point. The effect is a blue spot. A little experience will determine the amount of each color re-

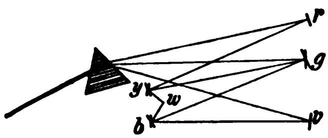

FIG. 194.—RECOMPOSITION OF PRIMARY COLORS.

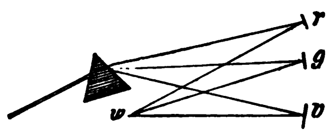

FIG. 195.—DIRECT UNION OF PRIMARY COLORS.

quired. The mirror in the violet should be much wider than the others. If either color predominates, cover up part of the mirror which is reflecting that color. When good yellow and blue have been obtained, reflect them by two other pairs of mirrors to a common point, *w*, where a spot of white light will appear. Vary the experiment by throwing the light from *r*, *g*, and *v* to one spot, as shown in Fig. 195. A good white should result.

332. The above requires some apparatus. If that cannot be had, procure some small sheets of colored gelatine, or pieces of colored glass representing as nearly as possible the prismatic colors, for a few experiments to follow.

Experiment III.—Hold a red glass close to one eye and a green glass close to the other, and look at a white wall or white lamp-shade. It will appear yellow. The optic nerve from one eye carries the sensation of green, from the other the sensation of red. These nerves meet before reaching the brain, and the combined impression is yellow. The effect is probably similar when the two colors are thrown together on the wall. Each eye takes up the two impressions, and they produce *in the brain* the impression of yellow. It will be difficult to produce the blue with the two pieces of glass or gelatine, because of the difficulty of procuring a true violet color in those substances. What is frequently called violet is purple, a mixture of violet and red.

333. Complementary Colors.—The second pair of mirrors in Fig. 194 reflect yellow and blue light to the wall and produce white. *Any two* colors which thus combining give

us the sensation of white are said to be *complementary* to each other. Blue and yellow are the best complementary colors, but green and purplish red make a very good pair. With the apparatus of Fig. 194 the combinations of all possible complements may be shown.

Experiment 112.—Hold a good yellow gelatine over one eye, and a good blue over the other, and look at a white surface. It will appear white. A green and a purple will do the same.

True complementary colors must represent all three primary colors. This is why blue and yellow are the best prismatic complements. One is green and violet, the other red and green. The other pair of complementary colors mentioned above—green and purplish red—contain all the primary colors. Either of the primary colors is complementary to the color which results from uniting the other two.

Experiment 113.—With two bright lamps and a ruler, arranged as in Fig. 142, hold a blue gelatine so that one of the lights will have to shine through it to cast its shadow of the ruler. The shadow cast by that lamp will be yellow, while the other shadow is blue. A green gelatine produces the effect of green and purple shadows. This is an effect of contrast. The yellow shadow in the first case is the only part of the screen not receiving *blue light*, and the eye makes it yellow. The eye when fatigued with any intense color may see the complementary color on suddenly turning to a white wall.

Experiment 114.—Paste a patch of black court-plaster on a bright green paper. Cover paper, patch, and all with white tissue-paper. The black patch will appear purple. The nerve-fibres sensitive to green are largely engaged with the general view of the paper, and the others being fresh give more than their normal impression from the thin reflecting material over the black patch. A green label printed in black, such as we see on hardware packages, will answer for the above.

334. **Mixtures of Paint.**—Two paints of complementary colors do not produce white. The eye does not receive the full color of either paint, but a residue of color only. Prussian blue and chrome-yellow produce a green paint. If the two cards of Experiment 112 be placed one over the other, the light coming through both will be green. This is because the colors are not strictly pure. *The blue* card allows blue and green to pass, but quenches

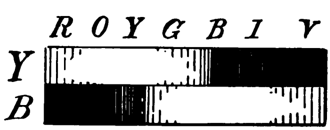

FIG. 196.—GREEN BY ABSORPTION.

all yellow and red. The yellow card transmits yellow and green, but quenches all blue and violet. Green, being the only light that can get through both, gives the color to the combination. In Fig. 196 the upper half, *Y*, shows the light which passes through the yellow card, and the lower half the light (or spectrum) of the blue card. The middle of the spectrum (green) is the only color left after both cards have absorbed and quenched their respective portions.

335. **Irradiation.**—The effect of light on the retina *spreads* to a perceptible extent. A flame appears larger than a black body of the same size. A white circle on black paper appears larger than a black circle on white paper. If from a distance of several feet we look at a crack in a shutter towards a bright sky, the width of the crack is much magnified.

FIG. 197.—EXPERIMENT IN IRRADIATION.

Experiment 115.—Go into a room whose windows are shaded by Venetian blinds, in *narrow* movable sets. Close one row, open the next row, and, going to the farther side of the room, look at the window thus fixed. If there is a bright sky beyond, the open slats will appear much longer than the closed ones.

336. **Blind Spot in the Eye.**—The part of the retina immediately at the end of the optic nerve is not sensitive to impressions of light. This is the "blind spot." Convince yourselves of its presence by the following:

Experiment 116.—Close the left eye, and with the right eye look

intently at the left-hand dot in this row. With the eye about 5½ inches from the paper the middle dot will disappear entirely. With the eye 11 inches from the paper, the right-hand dot disappears.

337. **Polarized Light.**—In Art. 256, polarized light was defined as that whose vibrations are all reduced to one

plane. The eye can detect no difference between polarized light and that which is not polarized. In Experiment 81 the beam of light was polarized by being passed through a slice of tourmaline. We may see that it is polarized by looking at it through a similar piece of tourmaline. A pair of tourmalines arranged for this purpose are called tourmaline tongs.

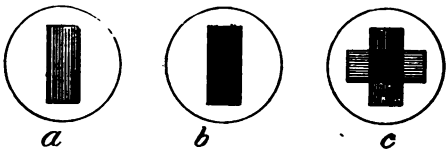

FIG. 198.—TOURMALINES PARALLEL AND CROSSED.

Experiment 117.—If one tourmaline be held between the eye and the window (close to the eye) and the other be held over it so that the light from the window must pass through both to reach the eye, the landscape may still be seen if the tourmalines be parallel. If, however, the tourmalines be placed at right angles with each other the light from the window will not reach the eye. The second tourmaline tells us that the light emergent from the first tourmaline is polarized, by quenching it in one position. In Fig. 198, *a* represents one tourmaline, *b* the two tourmalines parallel, and *c* the two crossed.

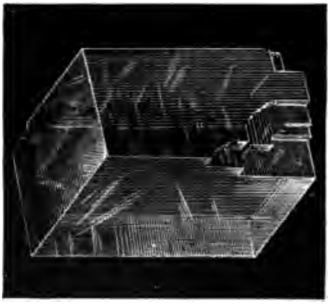

FIG. 199.—CRYSTAL OF ICELAND SPAR.

FIG. 200.—DOUBLE REFRACTION.

In all arrangements for the study of polarized light, the first crystal or reflector is called the *polarizer*, and the second the *analyzer*.

338. **Polarization by Iceland Spar.**—If a crystal of Iceland spar be laid on a printed page, there are certain positions in which all lines and letters appear double.

If the two images of any mark be examined with an analyzer, it is found that the light in both is polarized, and the planes of polarization are at right angles to each other.

Experiment 118.—Place a small piece of Iceland spar over a large period. Turn the spar until the period appears as two, one above the other. Then with a piece of tourmaline, held near the eye and lengthwise of the page, look at the double image. One only will be seen. Rotate the tourmaline quarter-way around. The other image only will be seen.

339. **The Crystalline Structure.**—Although the crystals of many minerals possess the property of double refraction and polarization, these phenomena are exhibited by Iceland spar to a degree of perfection far surpassing that of other substances. As stated in Art. 282, refraction of light is due to the fact that, although the ether exists and vibrates between the molecules of transparent substances, the vibrations are not *free*. In such substances as glass which has been melted and blown or cast into shape, the obstruction to the free vibration of the ether particles is *equal in all directions*, so that a beam of light having passed through glass comes out as *one* beam, and *unpolarized*. In *crystals*, however, such as Iceland spar, the molecules are regularly arranged around a certain line, or a series of parallel lines, extending through the crystal. The direction of these lines is the *optical axis* of the crystal. A beam of light passing through such a crystal in the direction of the optical axis emerges from the crystal as one beam and unpolarized. A beam passing through the crystal in any other direction emerges as two polarized beams. This is because the ether is so hampered by the molecules of the crystal that it vibrates more freely, or is more "elastic," in one direction than in others. The planes of greatest and least elasticity are at right angles to each other; the one being parallel to the axis, and the other perpendicular to the axis of the crystal. A beam of light passing into such a crystal on an oblique surface, and perpendicular to the axis, has its vibrations reduced to two planes, at right angles to each other. These have only to be separated to give two polarized beams. The separation is effected by the difference of elasticity in the two directions. That part of the light which vibrates perpendicularly to the axis is retarded more, consequently refracted more (Art. 283), than that which vibrates parallel with the axis. The two parts of the original beam therefore emerge from the crystal at different places and form the two beams.

340. The Nicol Prism.—A crystal of Iceland spar so cut that one only of the polarized beams is allowed to emerge constitutes a Nicol prism, the most efficient of all polarizers or analyzers. A small Nicol is inexpensive, and the class should, if possible, procure one. Otherwise use a tourmaline for experiments.

341. Rotation of Polarized Beam.—**Experiment 119.**—With the tourmalines crossed, as in Fig. 201, introduce between them a scale of mica, *m*, which may be split with a knife from the stove door. It may be necessary to turn the mica for a moment, but soon a position will be found in which the light will pass through the crossed tourmalines, mica and all.

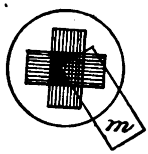

FIG. 201.—MICA BETWEEN TOURMALINES.

This is because the mica turns the plane of polarization, or "rotates" the polarized beam, so that it can pass the analyzer.

342. Many other Crystalline Substances possess this property of rotating a polarized beam, as well as some substances in solution in water. Of the latter class is sugar. A standard solution of a certain kind of sugar rotates the beam a certain number of degrees. The customs inspector, by examining a solution containing a weighed quantity of sugar from any barrel with a delicate graduated polariscope, can tell at once what percentage it contains of the kind of sugar which the sample claims to be.

Experiment 120.—Lay a pane of ordinary glass on a table or on the floor, so that the sun may shine on it making an angle of about 33° with the glass (57° with the perpendicular). The sunlight will be reflected

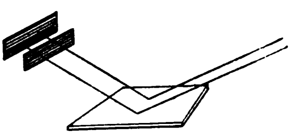

FIG. 202.—REFLECTED BEAM PASSING THROUGH TOURMALINE.

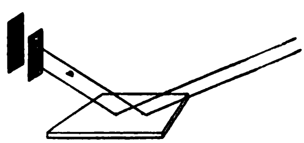

FIG. 203.—REFLECTED BEAM QUENCHED BY TOURMALINE.

to the wall. Hold in the light spot, near the wall, a tourmaline. The light will pass through when the tourmaline is horizontal, but not when it is vertical. It has been polarized by reflection from the face of the glass. See Figs. 202 and 203.

343. **Light is polarized when reflected** from glass at an

angle of about 57° with the perpendicular. A looking-glass will not do. Some other substances polarize light by reflection. A piece of glass held so that the light is reflected from it to the eye at the proper angle is also an analyzer.

344. **Colors by Polarization.**—Many substances that rotate polarized light (being themselves double-refracting and polarizing substances) not only restore the light, as the mica did in Experiment 119, but also give bright prismatic colors, which invariably change to the complementary colors when the analyzer is rotated one-fourth of the way around. One of the best substances for this purpose is a splinter of crystallized gypsum or selenite.

345. A class of ingenious students can find much entertainment and instruction in devising experiments in polarization. A single pane of glass, or a dozen panes together, are a good polarizer. If you have the dozen plates, the light transmitted through the glass is polarized as well as that reflected, but in the perpendicular plane. Vary experiments like this:

Experiment 121.—Stand outside a window which has a curtain drawn down inside, and with any form of analyzer examine the landscape, or the row of houses on the opposite side of the street, as they appear reflected in the window. The house or tree which occupies the proper position will disappear from view when the analyzer is horizontal, and in the place which it should occupy in the window you see the curtain through the glass! Hold a piece of mica between the analyzer and the window, and the reflection will be restored. Try several pieces of mica and of selenite, split thin. Some will probably give the interference colors, complementary when the analyzer is rotated 90°.

SUMMARY OF CHAPTER VI.

Light consists of minute and rapid vibrations of luminiferous ether which fills space and exists also between the molecules of most substances.

Substances which allow of the free vibration of the ether between their molecules are *transparent*, those which allow of no such motion are *opaque*.

The vibrations of light are at right angles to the direction of propagation, and in all planes.

The degree of illumination produced by a given light decreases as the square of the distance from the light increases.

Light travels through air with a velocity of more than 186,000 miles per second. It travels more slowly through *denser* substances, such as water, glass, and clear crystals, and rather more rapidly through a vacuum.

Light is *reflected* from surfaces which its waves cannot penetrate.

We see objects by the light *irregularly reflected* from them.

Light is *regularly* reflected by mirrors, and thus images are produced.

Images seen *in a mirror* or *through a lens* are *virtual* or *apparent* images. Images formed at the focus of a concave mirror or a convex lens, so that they *may be seen from any position*, are *real* images.

The light which illuminates our rooms during the day is reflected and *diffused* by the particles natural in the air.

Light entering a rarer or a denser medium *obliquely* is *refracted.*

Total reflection occurs only when a ray of light passing through a denser medium strikes the surface of a rarer medium at an angle greater than the limiting angle.

Convex lenses *converge* and concave lenses *diverge* rays of light.

The crystalline lens of the eye forms a real image on the retina.

The telescope and microscope form *real images* in the focus of the objective, and the observer sees *apparent images* of these through the eye-piece.

A triangular prism disperses a ray of light, and shows the colors which it contains. The colors thus separated constitute a *spectrum.*

A prism disperses all the radiant energy which encounters it, some of it as *heat*, some as *light*, and some as *chemical* energy.

The spectrum of a glowing or burning substance indicates what the substance is, and its condition (solid, liquid, gaseous).

A white body will reflect light of any color, a black body reflects no light, and a colored body reflects some only of the colors of the spectrum.

The color sense is believed to be dependent upon the action of three sets of nerve-fibres in the eye, one capable of transmitting *red* most easily, one *green*, and the other *violet.* These are called the *primary* colors, and white and all shades of color may be produced by properly blending them.

Light which has its vibrations reduced to one plane is *polarized.* This is effected by transmission through or reflection from a partly transparent substance.

The eye cannot detect polarization. It is detected by a second polarizing substance, which quenches the polarized beam in a certain position.

CHAPTER VII.

HEAT.

346. **What is Heat?**—Heat, as we know it by our nerves of sensation, and whose stupendous effects we witness in the work which it does for us, is a form of energy consisting of a rapid vibratory motion[1] of the molecules of the heated body, or of the ether contained between the molecules, or both. These vibrations traverse space in ether-waves as light does, and with the velocity of light. (Art. 257.)

347. **Radiant Energy and Heat.**—Though we speak of heat as traversing space in ether-waves as light does, it is difficult to conceive of heat existing *as such* in universal space, between the stars, and between the sun and planets. Our notion of heat is connected with a body—a *mass of matter*. We know that the sun is a mass, and that it is intensely hot. Much of the energy radiated from the sun is converted into heat in the earth and the objects on its surface, but as it traverses space we call it *radiant energy* rather than heat. (See Art. 313.)

348. **The Sun and the Earth's Heat.**—The earth is dependent upon the radiant energy of the sun for nearly all the heat which it enjoys. Not only our comfort, but the very life and growth of all organic forms depend upon it. Even the Arctic regions receive from the sun sufficient heat to render them habitable.

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[1] Prof. Tyndall has written a book entitled "Heat a Mode of Motion." This is an excellent treatise, and will give students a valuable lesson in the careful habits which are necessary to a scientific investigator.

349. **Chemical Action a Source of Heat.**—Chemical action is another source of heat.

Experiment 122.—Mix some strong sulphuric acid and water slowly together, stirring the mixture. They combine, and the vessel is heated. A thermometer will show the rise in temperature.[1]

The heat from combustion is from this source. There is a chemical union between the oxygen of the air and the carbon and hydrogen of the combustible. A certain amount of heat is necessary to start this action, but when started it keeps itself going by the heat which it generates.

Experiment 123.—Put some "quick-lime" in water; apply the thermometer to the water before and after. There is here chemical union between the lime and the water, and "slaked lime" is formed.

350. **Stoppage of Motion a Source of Heat.**—The stoppage of motion is a great source of heat.

Experiment 124.—Lay a nail on an anvil, and strike it two or three sharp blows with a hammer. Then quickly touch the nail to a little piece of phosphorus, or, if this is not to be had, give it more strokes and touch it to the head of a match. The phosphorus or the match will take fire.

We say the *motion is converted into heat.* This means that the motion of the hammer is changed into the vibratory motion of the particles of the nail, which in turn communicates itself to the particles of the phosphorus. It is an illustration of the *correlation of forces.*

351. **Illustrations of the Conversion of Motion into Heat.**—There are many illustrations of the conversion of motion into heat. Meteors, or "shooting-stars," are little stones which enter our atmosphere with great velocity. They strike so many particles of air, and so much of their motion is stopped, that they become intensely hot, and finally burn up, giving out the light by which we see them. All friction is accompanied by heat, for a similar reason. It is the stoppage of motion. Friction-matches, the heating of

[1] For this and similar experiments a thermometer should be procured *without* a frame, and with the markings on the tube.

axles, the Indian habit of rubbing two sticks together or of striking flints to light a fire, rubbing the hands to warm them, are illustrations.

352. It is believed that the heat of the sun is partly supported by the fall of bodies into it and the conversion of their motion into heat. As we know that the sun is continually expending its energies in all directions into space, we must explain in some way its sustenance, and the heat generated by the fall of bodies from some distance away would be many times greater than that which would be produced by their combustion were they composed of solid coal.[1]

353. **Mechanical Equivalent of Heat.**—A given amount of motion stopped will always produce the same amount of heat. The amount of motion in a body depends on two things,—the mass and the velocity,—and is measured in foot-pounds. A pound weight falling 772 feet produces heat enough on striking, or on being stopped, to raise the temperature of a pound of water one degree Fahrenheit. It will thus be seen that the one unit of heat (Art. 360), as a working agent, is equal to 772 foot-pounds of mechanical energy.

This number 772 is called the *mechanical equivalent of heat*, and was determined by Joule[1] in a number of ways, one of which was the following. He had a box of water in which were a number of paddles which churned the water. These paddles were turned by a weight falling. The weight being known, and the space through which it fell, also the difference of temperature of the water at the beginning and at the end of the fall, the amount of fall necessary to produce an increase of 1° was easily calculated. Thus, a 100-pound weight falling through 20 feet would perform 2000 units of work. If this raised the temperature

[1] See Sharpless and Philips's "Astronomy," Art. 47.

[1] James P. Joule (jool), an English physicist (1818–1889).

of one pound of water 2.59°, then to raise it 1° there would be 2000 ÷ 2.59 = 772.2 units of work expended.

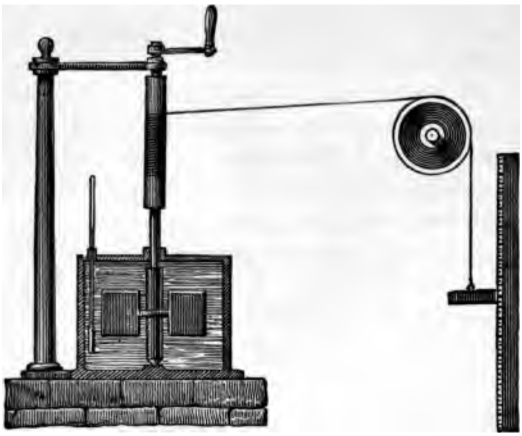

FIG. 204.—JOULE'S MACHINE.

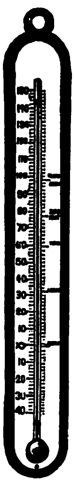

FIG. 205.—THERMOMETER.

354. Conservation of Energy.—If now this heat could all be utilized in an engine, it could just lift the weight to the point from which it fell. We have another illustration of the "conservation of energy." The mechanical motion is destroyed, but an equivalent in molecular motion (heat) is produced. A certain amount of mechanical motion always produces the same amount of heat, and if this could all be collected it would in turn reproduce the mechanical motion. The energy is not lost, but is converted into another form. Heat is converted into mechanical motion in locomotives. This goes again into heat in the friction of the bearings of the different axles of the train, of the wheels against the track, and of the train against the air.

355. Thermometers.—*Temperature is measured by thermometers.* The most common thermometer is the

mercury thermometer, and it depends upon the principle that heat expands the mercury in a tube and cold causes it to contract. It consists of a bulb with a tube attached. The bulb and part of the tube are filled with mercury, and the remainder contains no air, but only a little vapor of mercury. To construct a thermometer the mercury is heated in the bulb, and when the tube is full of vapor it is sealed up at the upper end. Then in cooling most of the vapor condenses and leaves nearly a vacuum in the upper part of the tube.

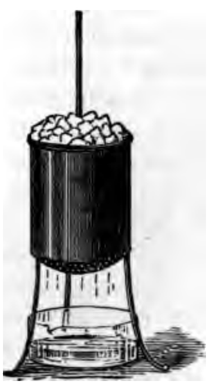

FIG. 206.—TO FIND THE FREEZING-POINT OF A THERMOMETER.

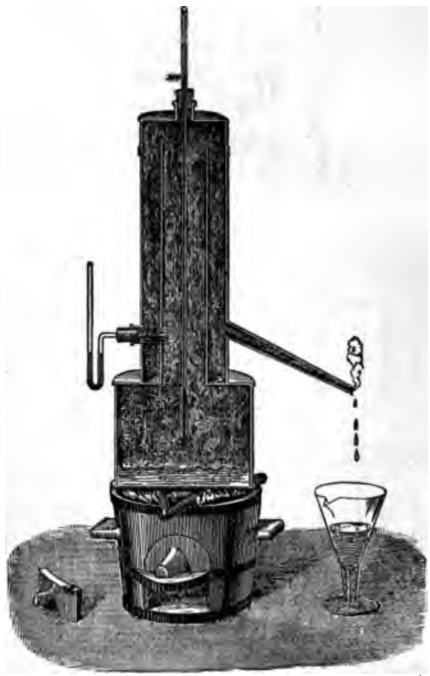

FIG. 207.—TO FIND THE BOILING-POINT OF A THERMOMETER.

356. Freezing-Point and Boiling-Point.—There are several ways of graduating thermometers, but in all there are

two points which must be determined. These are the freezing-point of water and the boiling-point of water.

To determine the first, the bulb is kept in a mass of chopped ice or snow till the mercury settles at a definite place. This place is then marked.

To determine the boiling-point, the bulb is placed in boiling water, from which the steam is allowed to pass freely and to envelop the tube. The point at which the mercury settles is then also marked.

357. **Graduation.**—We have now two marks, and it is necessary to graduate the thermometer between them. There are two common methods of doing this.

358. **Centigrade Thermometers.**—The first is the Centigrade method, used in France, and by scientific people everywhere. The freezing-point is marked 0°, and the boiling-point 100°, and the space between is divided into 100 equal divisions. Divisions of the same size are then continued above 100° and below 0° as far as necessary.

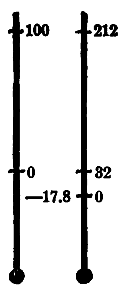

FIG. 208.—CENTIGRADE AND FAHRENHEIT THERMOMETERS.

359. **Fahrenheit Thermometers.**—The other is the Fahrenheit method, used by people in general in England and the United States. The freezing-point is marked 32°, and the boiling-point 212°, and the space between is divided into 180 equal divisions, which are continued up and down. Both methods will be used in this treatise, the addition of the letter C. or F. stating which.

As 100° C. are equivalent to 180° F., 5° C. are equivalent to 9° F.; hence any number of degrees of one scale can be reduced to its corresponding number of the other.

Exercises.—1. To what marking on F. scale does 40° C. correspond?

$$\begin{aligned} \text{Since } 5^\circ \text{ C.} &= 9^\circ \text{ F.,} \\ 1^\circ \text{ C.} &= \tfrac{9}{5}^\circ \text{ F.,} \\ \text{and } 40^\circ \text{ C.} &= 72^\circ \text{ F.} \end{aligned}$$

This gives the number of F. degrees above freezing-point, which is 32° above zero. Then the reading of the F. scale would be 104°.

2. To what marking on C. scale does 122° F. correspond? *Ans.* 50°.
3. To what marking on F. scale does 10° C correspond? *Ans.* +50°.
4. To what marking on C. scale does —40° F. correspond? *Ans.* —40°.

360. **Unit of Heat.**—A unit of heat is a definite quantity of heat, or the heat capable of doing a definite amount of work. (See Art. 20.) The English unit referred to in Art. 353 is the amount of heat necessary to raise the temperature of one pound of water one degree Fahrenheit. This unit has no other name.

The "Calorie," derived from the Metric system, is the unit now in the best use. It is the *amount of heat required to raise the temperature of one kilogram of water one degree Centigrade.*

361. **Specific Heat.**—The specific heat of any substance is strictly its capacity for heat, and is measured by the number of Calories required to raise the temperature of one kilogram of that substance one degree Centigrade. Different substances vary greatly in Specific Heat, but as a rule all common substances (except hydrogen) are less than one; that is, they have less capacity for heat than water has. The specific heat of iron is about .1; that of air is about .2375.

Experiment 125.—Put a pound of water in a tin cup on a warm stove. Stir with a thermometer while the temperature rises say 10°. Note the *time*. Replace the water with some other safe liquid, *e.g.*, paint oil, and note the time. The oil will require less time for the same rise in temperature, it takes in less heat, its specific heat is less.

Experiment 126.—Put an iron pound-weight into boiling water for a few minutes, then immediately into a pound of cold water whose temperature is known. Soon it will be found that the iron has lost about ten times as much heat as the pound of cold water has gained.

362. **Heat produces Expansion.**—The general effect of heat is to expand bodies. An iron ball that will just pass through a ring when cold, is too large when hot. An iron rod will measure a little longer when heated. The rails of a track laid in summer will be separated in winter.

The expansion is accomplished by the separation of the

molecules, and the separation is caused by their rapid vibration. This requires more room, and overcomes to some extent the force of cohesion. The force of separation is so

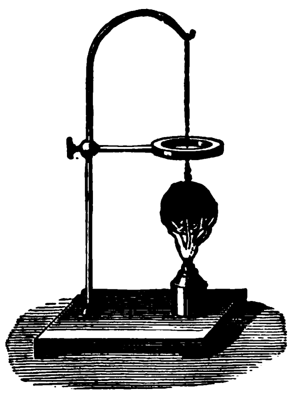

FIG. 209.—EXPANSION OF SOLIDS BY HEAT.

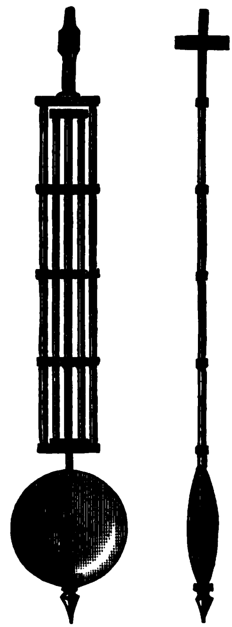

FIG. 210.—EXPANSION BY HEAT.—GRIDIRON PENDULUM.

great that it is generally useless to try to counteract it. In iron buildings and bridges arrangements are made so that the pieces can be allowed to expand without injury.

363. **Melting and Evaporation by Heat.**—As the heat is increased, the particles are more and more agitated and dispersed, and the force of cohesion becomes less and less, until finally the body changes from a solid to a liquid. If heat is still applied to it, the molecules are farther separated, until they reach such a distance apart that no cohesive *force acts* between them, and the liquid becomes a gas.

Melting and evaporation, then, must be considered as the shaking apart of the molecules by the vibratory motion communicated to them, which vibratory motion is heat.

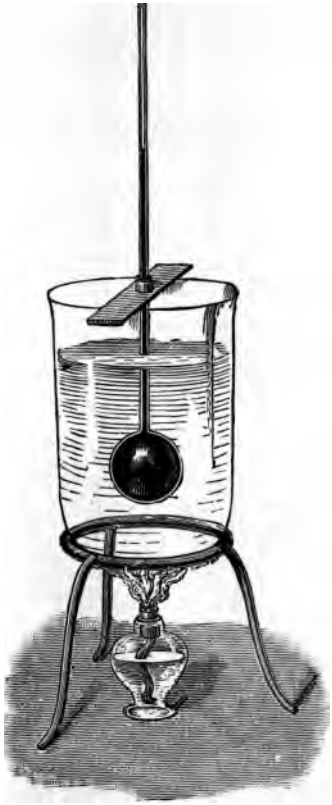

FIG. 211.—EXPANSION OF LIQUIDS BY HEAT.

FIG. 212.—EXPANSION OF AIR.

364. **Expansion of Liquids.**—The expansion of liquids can be readily seen by

Experiment 127.—Partly fill with colored liquid a glass tube with a bulb. Immerse the bulb in water, and apply heat gently. The colored liquid will rise in the tube. Thermometers are based on the principle of the expansion of liquids by heat.

365. Expansion of Gases.—The expansion of gases can be seen by the following:

Experiment 128.—Heat a flask filled with air, and conduct a tube into a vessel of water. The expanded air will be driven out of the tube, and will bubble up through the water.

Experiment 129.—Tie up a bladder or a toy balloon partly filled with air. Heat it, and the balloon will expand.

In Experiment 128 it is evident that the air remaining in the flask will weigh less after being heated than did the original, for there are fewer particles.

366. Law of Expansion of Gases.—There does not seem to be any general law which can be said to govern the cases of expansion of solids and liquids, since they are so diverse in their qualities. But a true gas (not a vapor) will expand according to a certain law, whatever its composition. *If kept under a constant pressure as it expands, it will increase $\frac{1}{273}$ of its volume at 0° for every Centigrade degree of heat given it.*

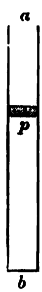

Fig. 213.

To illustrate this, suppose p to be a piston fitting closely in a tube ab, but moving up and down without friction, and suppose the portion pb below the piston to be filled with gas at a temperature of 0° C. If the temperature be raised to 1°, the gas will expand $\frac{1}{273}$ of its volume, and will lift the piston; if raised to 2°, it will expand $\frac{2}{273}$ of its original volume; and so on.

We can also carry the process the other way. If the gas be *cooled* 1°, the resulting volume will be $\frac{272}{273}$ of the original; if 2°, $\frac{271}{273}$; and so on down. If we could cool it to —273° it should have no volume at all. The molecular vibrations which constitute heat would then cease, and the former gas have no heat at all. This point, —273° C., is therefore called the *absolute zero of temperature.* Of course, in practice, gases become solid long before reaching the absolute zero of temperature.

The *absolute temperature* of a body is the number of degrees above the absolute zero.

The absolute zero on the Fah. scale is —459.4°. **How is this?**

367. **Relation between Heat and Volume.**—When a body is heated, some of the heat goes to expand it, so that the temperature is not so great as it would otherwise be. If the piston in Fig. 213 were held down so that the gas could not expand, the same amount of heat applied to it would raise its temperature higher. In expanding, part of the heat is used up in doing the work of separating the molecules. This heat is consumed continuously in keeping the molecules apart, and any abstraction of heat will allow them to come together again. Hence cold produces contraction. Cooling is the loss of vibratory motion, and as the motion ceases, the molecules approach one another.

Now, if the expansion is produced by a force, without the application of any external heat, cold is produced. For part of the heat previously in the body is now consumed in maintaining the separation of the molecules. The sudden stretching of a wire lowers its temperature.[1]

368. **Heat and Fusion.**—When heat is applied to a solid body so as to raise its temperature to the point of fusion or melting, the addition of more heat will not further raise the temperature till the body is completely melted. The heat does the work of driving the molecules apart, and so changing it from solid to liquid. A certain amount of heat is consumed in producing the liquid form.

Experiment 130.—Place a piece of ice in a vessel over a slow fire. As the ice melts, keep it well stirred, and frequently apply a thermometer. It will indicate the freezing-point until all the ice is melted.

Although much heat has gone into the ice, it has been destroyed as sensible heat, and is employed in keeping the molecules at such a distance from one another as to make a liquid. This energy, which does not show itself by a thermometer, is called *latent heat.* It requires 80 units of heat to melt ice, or as much as would raise the same weight of

[1] India-rubber seems to be an exception to both laws. When stretched, heat is produced, and the application of heat contracts instead of expanding it.

water through about 80° C. of temperature. When the ice freezes, the same amount of heat is given out.

Melting, then, implies the using up of heat. As this heat comes from external sources, its effect is to reduce their temperature. Freezing, on the contrary, liberates heat and raises the temperature of surrounding objects. Melting causes cold, and freezing causes heat.

Experiment 131.—Mix some chopped ice with salt, and stir well together, and keep a thermometer in the mixture. It will indicate a temperature much below the freezing-point. The salt makes the ice melt, and so causes cold. This is the common freezing mixture used by ice-cream-makers.

Experiment 132.—Pulverize some nitrate of ammonium in a thin glass vessel, add water, and stir. As the salt dissolves, insert the bulb of a thermometer. The mercury will rapidly fall. Place the vessel on a wet board. It will freeze to it.

Here the rapid solution of the salt in water abstracted heat from the vessel, from the thermometer, and from the board. Hence not only fusion, but solution, causes cold.

Define fusion and solution.

369. **Heat and Evaporation.**—Similar effects are seen in the passage from the liquid to the gaseous state. Heat is required to keep up the gaseous condition of a body: hence evaporation takes heat from surrounding objects and causes cold, and condensation liberates it and raises temperature.

Experiment 133.—Pour a little ether in the palm of the hand. As it rapidly evaporates, considerable cold is felt. Dip a thermometer in ether and quickly remove it. The ether which adheres will evaporate and take heat from the mercury in the bulb.

370. **Freezing in Red-Hot Vessels.**—Sulphurous acid—the gas formed when sulphur is burned in air—is capable of being made liquid by passing it through a tube immersed in a freezing mixture of ice and salt. If a crucible be heated red-hot, a little water put in it, and immediately the liquid sulphurous acid poured on it, so great a degree of cold will be produced by the sudden vaporization of the acid that the water will be frozen in the red-hot crucible.

371. **Solidification of Gases.**—If a gas be condensed by

great cold and pressure, and then suddenly be allowed to expand by passing out through a fine tube, the great expansion and evaporation will cause such cold that the gas will be liquefied, and in some cases solidified. Hydrogen, the lightest of all gases, has been made solid by this method, and been heard to rattle on the floor like minute hailstones.

372. **Cryophorus.**—A cryophorus is an instrument consisting of two glass bulbs connected as in Fig. 214. One of these is partly filled with water, and the rest of the apparatus is made as nearly as possible a vacuum. This is soon filled with vapor of water, which passes off under the low pressure. If the *other* bulb is placed in a freezing mixture of ice and salt, the vapor is condensed, and evaporation goes on so rapidly from the water that it finally freezes.

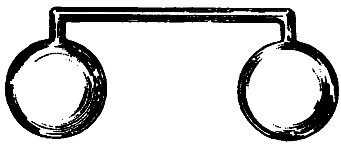

FIG. 214.—CRYOPHORUS.

373. **Artificial Ice.**—In India, ice is made by putting water into pots of porous earthenware. The water evaporates from the outside of these so as to freeze the water on the inside. Artificial ice is produced in warm countries on a large scale by passing liquid ammonia through pipes which line the bottom and sides of a vessel of water. The liquid is quickly converted into a gas, and this takes so much heat from the water that it is frozen.

Experiment 134.—Heat some water, having the bulb of a thermometer in it during the operation. The mercury will gradually rise till it reaches the boiling-point; after which, if the steam is not confined, it will not indicate any higher temperature till the water is boiled away.

374. **Latent Heat of Steam.**—In this experiment the heat applied after the water commenced to boil is all expended in changing the liquid to a gaseous form, and becomes *latent* in the gas. To change water into vapor requires about 537 times as much heat as would raise the same amount through one degree of temperature,—in other words, 537

units of heat. This number 537 is called the latent heat of steam, as 80 (see Par. 368) is the latent heat of water. They represent the number of degrees of heat stored up and kept in constant use in maintaining the condition of the body, and which will not show itself by a thermometer.

375. **Heat expended in Fusion and Evaporation.** — To show the meaning of these figures, let us suppose a mass of ice at a temperature of —10° C., and let it be heated from a source which gives it 1° a minute. In 10 minutes it will be brought to 0°. In 80 minutes more it will be all melted, but it will still be at 0°. In 100 minutes more it will be raised to a temperature of 100°, and will begin to boil. In 537 minutes more it will all be converted into vapor at a temperature of 100°. This vapor can then be increased in temperature by the application of heat.

Exercises.—1. Why does moist clay contract when heated?

2. Why do telegraph-wires hang down more in summer than in winter?

3. Why does a wheelwright put the tire on the wheel hot?

4. Will sugar placed in coffee cool it more than the same amount of sand at the same temperature? why?

376. **Expansion by Freezing.**—The general effect of cold is to contract. There are exceptions to this in the case of water under certain circumstances, and of a few other substances. When water is reduced in temperature it contracts in volume till it reaches the temperature of 39° F. or 4° C., after which it begins to expand. This expansion amounts to about $\frac{1}{14}$ of its original bulk, and shows itself in bursting vessels in which it is contained. Heavy iron shells can be thus burst. Fig 215 represents the effects of this expansion. A large shell was filled with water and the hole tightly stopped by a wooden plug. When it froze, the plug was forced out with great velocity and a cylinder of ice eight inches long issued from the hole. At another time the shell split in two, and a sheet of ice was forced out.

This lightness of ice causes it to float on water. If it

continued to contract as it cooled, it would sink, and all of it would be at the bottom of the ponds.

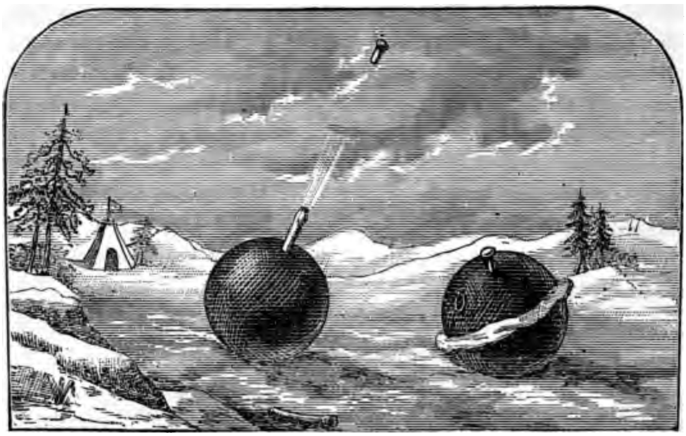

FIG. 215.—EFFECTS OF FREEZING.

377. **Freezing.**—Freezing is the formation of crystals. They begin to form around the edge of the pond or around some object floating in the water, and add one to another till the whole surface is frozen. The process can be watched by the following method.

Experiment 135.—Wet a clear piece of glass with a solution of sulphate of copper or chloride of ammonium, and hold it between you and the light. In a little while, as the water dries, the crystals will begin to shoot out in various directions over the glass. The effect is much improved if the plate is placed in a projecting lantern and the formation of crystals shown on the screen.

378. **Melting.**—Melting is the reverse process from freezing. When the temperature is raised above the freezing-point the crystals gradually dissolve into water. This goes on all through the mass, and the ice becomes rotten before it disappears.

379. **Evaporation and Boiling.**—Evaporation goes on at all temperatures. Ice is converted into vapor without passing through the intermediate stage of liquids. Clothes hung out in cold weather will become dry while the tem-

p

perature is all the time below the freezing-point. But the process goes on the more rapidly the higher the temperature. As water is slowly heated, steam passes away from its surface with greater rapidity until, when a certain temperature is reached, steam begins to form all through its mass. This, being lighter than water, is forced up through it to the top. This is *boiling*. The heat being applied at the bottom, that portion is most heated, and steam is there formed most vigorously. Not only the steam but also the heated water, being expanded, rises, and the other water takes its place, to be in turn heated. Thus there is a constant circulation.

Experiment 136.—Add a little chalk-dust from the blackboard to water in a glass flask, and heat it; watch the circulation of the water by the aid of the particles of dust.

In such experiments wipe the flask dry on the outside, and apply the heat gradually at first.

FIG. 216.—BOILING AS AN EFFECT OF REDUCED PRESSURE.

380. **Relation of Boiling-Point and Pressure.**—The boiling-point varies with the pressure. By exhausting the air over water it can be made to boil at a much lower temperature. Whenever the tension of the vapor equals the pressure on the liquid, boiling begins.

Experiment 137.—Boil some water in a flask, and remove the lamp. When the boiling has ceased, cork the flask, invert it, and pour some cold water on its base. The boiling will begin again. The cold water condensed the vapor and reduced the pressure.

This principle is used in the manufacture of certain dye-stuffs, and in sugar-refining, where it is desirable to evaporate the water at a low temperature. A partial vacuum is formed in the boiler, and the steam, as fast as it passes off, is condensed by a falling spray of water.

As we ascend a mountain the boiling-point lowers. An approximation to the height may be formed in this way: Roughly, the height in feet will be found by multiplying 600 by the number of degrees below 212° F. at which water boils.

Questions.—1. On a certain elevation water is found to boil at 200° F.: what is its height? $12 \times 600 = 7200$ feet, nearly.

2. A mass of gas at 60° C. and under a pressure of 30 inches measures 100 cubic inches: what will be its volume at 40° C. and under a pressure of 28 inches?

Solution.—At 60° its volume will be $\frac{60}{273}$ greater than at 0°; at 40°, $\frac{40}{273}$ greater. Now, 100 cubic inches $= 1\frac{60}{273}$, or $\frac{333}{273}$, its volume at 0°. Hence

$$\text{Volume at } 0° = \tfrac{273}{333} \times 100 = 81.9.$$
$$\text{Volume at } 40° = \tfrac{313}{273} \text{ of } 81.9 = 93.8.$$

This is the volume under 30 inches pressure. Under 28 inches, by Mariotte's law, the whole will be $\frac{30}{28}$ of $93.8 = 100.5$ cubic inches.

3. A mass of gas at 0° C. occupies a litre: what will be its volume at 546° C. under the same pressure? *Ans.* 3 litres.

381. **Steam.**—Steam occupies about 1700 times as much space as the water which produces it. In other words, a cubic inch of water will make about a cubic foot of steam.

382. **Distillation.**—Condensation is the reverse of evaporation. It takes place whenever the vapor is reduced in temperature below the boiling-point of the liquid. This is what causes the formation of dew, clouds, and rain.[1] Distillation is the condensation of certain portions of a liquid which separate from contained solids, or pass off at a lower temperature than the remainder. In this way water can be separated from the impurities which it contains, and alcohol from the water with which it is mixed.

The instrument by which this is effected is a *still.* A

[1] This subject will be found more fully treated in the chapter on meteorology.

retort containing the liquid is heated and the vapor passed over into a "worm," which is kept cool by being immersed

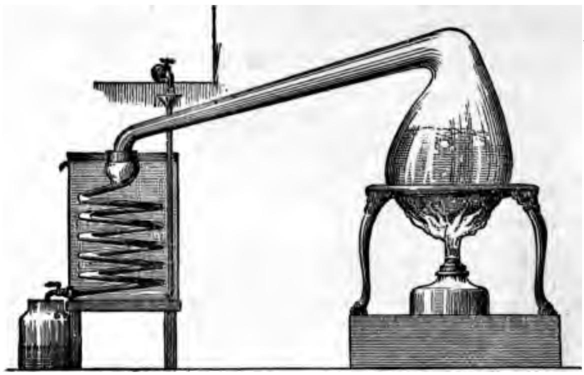

FIG. 217.—STILL.

in cold water. Here the vapor is condensed and runs out at the lower end, while the solid impurities or the less volatile liquids remain in the retort.

Experiment 138.—Drop a little water on a piece of iron heated to about 150° C. It will form into a drop and dance about the surface, and not evaporate very rapidly. Allow the plate to cool. At a certain temperature the drop will break, spread over the iron, and almost immediately change to vapor.

In this case the great heat of the plate causes such a down-rush of steam that the drop rests on a cushion of steam, and not on the plate. This fact can be readily seen by

Experiment 139.—Place a candle in the right position, and you can see light between the drop and the plate.

TRANSMISSION OF HEAT.

383. **Transmission of Heat.**—Heat travels through ether just as light does. The vibrations of the heated body are communicated to the particles of ether in contact with them, these act on the next, and so the motion is extended. The heat- and the light-rays are, partly at least, exactly the same rays. Some rays give us sensations of both light

and heat, some of heat only; hence heat- and light-rays, being largely the same, follow the same laws. Heat, like light, decreases as the square of the distance increases

FIG. 218.—REFRACTION OF HEAT BY A BURNING-GLASS.

(see Art. 261); it is refracted in accordance with the law stated in Article 285, and it is reflected, making the angle of incidence equal to the angle of reflection.

384. Luminous and Dark Heat.—The laws are the same whether the heat comes from a glowing body, like a candle or the sun, or from a dark body, as a vessel filled with hot water. In the one case we have *luminous heat*, and in the other we have *dark heat.*

385. Radiation and Radiant Heat.—The passage of heat from a heated body is called *radiation*, and heat on its passage is *radiant heat.*

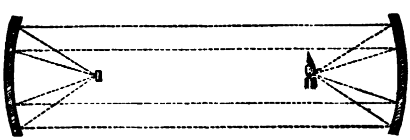

FIG. 219.—REFLECTION OF HEAT.

386. Reflection of Heat.—To prove that dark heat undergoes reflection, we can place a vessel of boiling water at the principal focus (see Art. 274) of a con-

cave mirror, when the heat-rays will be reflected; and if collected by another concave mirror, a thermometer placed at *its* principal focus will show a decided increase of temperature.

If a piece of ice is used instead of the vessel of hot water, the mercury falls. This would seem to indicate that *cold* is also reflected. Such is not the case. The cause of the fall is that the thermometer parts with its heat faster than the ice does, and it goes to the ice to raise its temperature, or to melt it.

To prove the refraction of heat we have the ordinary "burning-glass."

387. **Heat Reflected, Diffused, Absorbed, and Transmitted.**—Like light, all the heat which falls on a body is not reflected. Some of it is diffused (scattered in all directions), some of it goes into the body, and is either used up in doing work among the molecules or is transmitted.

388. **Different Bodies have Different Effects.**—Different bodies differ greatly in their power of radiating, of transmitting, of reflecting, and of absorbing heat.

389. **Difference in Radiation.**—If there be three vessels of equal size filled with hot water, one made of polished tin, one coated with isinglass and one with lamp-black, then in the same time there will be eight times as much heat *radiated* by the lamp-black as by the tin, and seven times as much from the isinglass as from the tin. As a general rule, metallic bodies are poor radiators, and the brighter and smoother the surface the poorer radiators they become. Good reflectors are commonly poor radiators, and the reverse. A body that radiates well will absorb well and reflect badly.

390. **Difference in Transmission.**—As regards *transmission* of heat, certain substances which are opaque to light allow heat to pass freely, and some transparent to light entirely cut off the heat. In the chapter on light we learned that blue glass allowed blue rays to pass through

and cut off the red: in the same way thin metallic foil will allow luminous rays to pass and cut off almost all the dark heat. Bad radiators are bad transmitters, for the bad radiators, like polished tin, *reflect* much of the heat that falls on them, and so transmit but little.

391. **Special Substances.**—Lamp-black (the soot from lamps) is an excellent absorber; it transmits no heat and reflects but little. Polished silver is a good reflector; it transmits nothing and absorbs very little. Rock-salt in transparent crystals transmits nearly everything; it absorbs none and reflects but little. Crystals of alum, equally transparent, will absorb nearly all the heat and transmit almost none. Ice is also a very poor transmitter.

392. **Dr. Franklin's Experiment.**—Dr. Franklin made the experiment of putting pieces of cloth of different colors on snow when the sun was shining. He found that the dark colors melted themselves into the snow farther than the light, from which he inferred that they were in general better absorbers. This is true in so far as it relates to luminous heat, but in the case of dark heat, such as we get from a stove, color does not seem to make any difference.

393. **Effect of Screens.**—A screen placed in front of a fire protects from heat. But, as it receives heat itself, it becomes in time a source of radiation. We do not feel the radiation so strongly, because the heat which it intercepts it sends out in all directions, and hence not so strongly in any one.

Exercises.—1. Should stoves be kept bright if we desire to have the most heat from them? Should teapots be of polished metal? cylinders of steam-engines?

2. Which is cooler in the direct rays of the sun, light clothing or dark? in a house by a hot stove?

3. If we had a convex lens of alum and one of rock-salt exposed to the sun, in the focus of which would be the higher temperature?

4. How much is the heat diminished by moving twice as far from its source?

5. The dark heat-rays are found near the red end of the spectrum: which have the more rapid vibration, the dark or the luminous waves?

6. Is a glass screen as effective in front of an open fire as in front of a stove?

CONDUCTION OF HEAT.

394. **Conduction of Heat.**—When heat travels along by communicating motion from one particle of a body to another, the movement is called *conduction of heat.* Radiation is movement through ether, and radiant heat has the same velocity as light. Conduction is a comparatively slow process.

Experiment 140.—Heat one end of an iron rod to which nails are stuck by little pieces of wax. The nails will drop off one by one as sufficient heat reaches them to melt the wax.

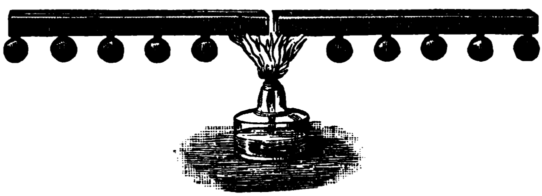

FIG. 220.—CONDUCTION OF HEAT.

395. **Different Conducting Power.**—Different bodies differ in their power to conduct heat.

Experiment 141.—Hold an iron rod in the fire till it begins to feel hot. Hold a glass rod the same time, no perceptible increase of heat is felt.

Experiment 142.—Coat bars of various substances with wax, and place them all with one end in hot water. Notice how far on each the wax melts.

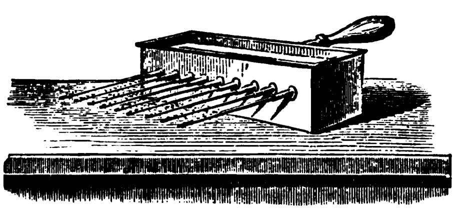

FIG. 221.—DIFFERENT CONDUCTING POWER.

396. **Conducting Power of Metals.**—The following table gives the relative conducting power of certain metals:

Silver	100	Iron	12
Copper	74	Lead	9
Gold	53	Bismuth	2
Tin	15		

397. **Conducting Power of Water.**—Water is a poor conductor of heat.

Experiment 143.—Put a piece of ice in a test-tube, and a weight to hold it down. Nearly fill the tube with cold water. By applying heat near the top the water may be made to boil without melting the ice at the bottom.

FIG. 222.—POOR CONDUCTING POWER OF WATER.

398. **Conducting Power of Air.**—Dry air is a poor conductor of dark heat, a better one of luminous heat, but moist air is a worse conductor of both dark and luminous heat. The sun's heat comes to us through the air and heats up the earth. This then radiates dark heat, part of which is retained by the moist air surrounding it.

On high mountains the sun's luminous heat penetrates the rare air without warming it, and heats the mountain-tops. But the radiated heat from them is not retained, but quickly passes off, leaving the air cold. A cloud or fog over the mountain would change all this.

The glass of a hot-house produces the same effect as the moisture of the atmosphere.

An open fire gives out luminous heat, which penetrates the air of a room readily and warms up the surfaces of solid bodies. The heat from a stove or a furnace on the

contrary, is more retained in the air. In the one case we are kept warm by direct radiation, in the other by living in a warm atmosphere.

Clothing is especially useful in retaining a layer of warm air next the body. This by its poor conducting power prevents the passage of heat outward.

399. Sensation of Heat.—Our *sensation* of heat depends largely on the conducting power of the substance with which we are in contact. A carpet and an oil-cloth lying side by side in a cold room are actually of the same temperature, but if we step on both with bare feet, the oil-cloth, being the better conductor, conducts the heat from the foot the more rapidly, and so *seems* colder. Hot bodies —*e.g.*, iron and wood in sunshine—give the opposite sensation, the better conductor seeming hotter.

Exercises.—1. Why is a glass tumbler more readily cracked by hot water than a vessel of better conducting power?

2. Why are the handles of teapots often made of glass or porcelain?

3. Why is woollen clothing warmer than cotton?

4. Why can a man plunge his hand into molten iron without being burned?

5. A brass cylinder covered with thin paper may be held in a flame for some time without having the paper scorched; not so when the cylinder is made of wood: why is this difference?

6. Why do hollow walls and double windows keep a house warm?

7. Would a hot-house be effective if heated by a stove from above instead of by the sun?

8. Why does the coming of clouds frequently make it warmer?

9. Are our sensations safe judges of temperature? Having had one hand in ice and the other in hot water, what will be the effect if we plunge both into tepid water?

CONVECTION OF HEAT.

400. Convection of Heat.—When a liquid or a gas is heated from below, the warm particles rise and are replaced by colder heavier ones. This makes constant circulation, which carries the heat about. This method of conveying heat by actual transmission of the particles of water is called *convection of heat.*

This can be well observed in the boiling of water, as seen *in Experiment* 136.

The diffusion of heat by currents is shown on a large scale in the Gulf Stream. This great body of warm water, which is a result of the heating of the earth at the equator, conveys this heat to the coasts of England and Norway.

THE STEAM-ENGINE.

401. **History of the Steam-Engine.**—About the year 1700 a machine to pump water out of mines by the aid of steam was invented and used in England, but about 1775 James Watt,[1] a Scotch mathematical instrument-maker, invented, and soon after brought almost to its present perfection, the stationary engine. The first locomotive-engine was built and run in 1804 or 1805 in England. But it was not until 1829 that the first really efficient locomotive was built by George Stephenson,[1] an Englishman.

402. **The Stationary Engine.**—Fig. 223 shows the essential features of the stationary engine. M is the boiler, where the steam is generated. At first we will suppose the valve *b* to be shut and *a* to be open. The steam will pass from the boiler through *a* and drive the piston, P, to the bottom of the cylinder. *a* is now closed and *b* and *d* are opened. While the steam is now passing through *b* to the under side of the piston and pushing it up, that steam which was above the piston is rushing through *d* down to the condenser, I, where it is condensed by the cold water there, leaving a vacuum above the piston, so that there is no obstacle to its ascent. When it reaches the top of the cylinder again, *b* and *d* are closed and *a* and *c* opened, and so on constantly. The figure shows how the up-and-down motion of the piston turns the fly-wheel, R, and thence by a belt or otherwise the machinery is set in motion.

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[1] Watt and Stephenson were two of the greatest benefactors to mankind that ever lived. Samuel Smiles has written lives of both these men that would be exceedingly interesting and valuable to every [illegible] lies *this* book.

403. **The High-Pressure Engine.**—The condenser adds much machinery to the engine, and requires a constant supply of cold water. Many engines, therefore, have no condenser; *d* and *c* open directly into the air. The air condenses the steam and itself fills up the vacuum, so that the piston in returning has to drive the air out of the cylinder ahead of it. *With* a condenser the piston is driven back through a vacuum, so that there is no resistance; *without* it the piston must be driven against the pressure of the atmosphere, nearly 15 pounds per square inch.

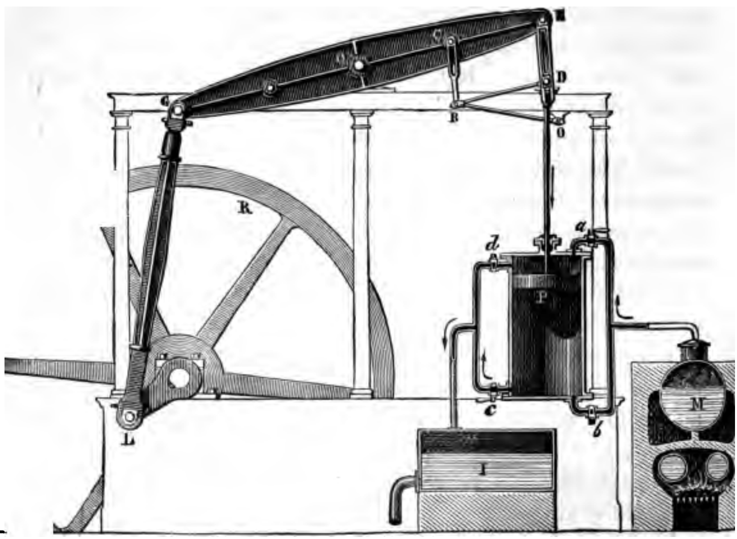

FIG. 223.—STATIONARY ENGINE (LOW-PRESSURE).

When there is no condenser, the pressure of the steam must be about 15 pounds per square inch greater or higher to do the same work: hence an engine without a condenser is called a *high-pressure engine*, while one having a condenser is called a *low-pressure engine*. Almost all small stationary engines are high-pressure. This is especially true of *portable* engines, such as steam fire-engines, engines for work-

ing thrashing-machines, portable saw-mills, and the like. A high-pressure engine of course takes more fuel to do the same work. In a high-pressure engine the steam escapes from the cylinder in puffs, and this puffing is characteristic of this kind of engine.

404. **How the Valves are worked.**—In Fig. 223, for the sake of simplicity, it is supposed that the four valves are worked by hand. Fig. 224 shows how one valve does the work of all four. In the right-hand figure the valve is raised, which allows the steam coming in by the pipe on the left to flow into the lower part of the cylinder, while the peculiarly-shaped valve, called a D-valve, connects the pipe from the other end of the cylinder with the opening *o*, which leads into the condenser. When the piston reaches the upper end of the cylinder, an arm, worked by the engine itself, pushes the D-valve down, as seen on the left, and the upper part of the cylinder is connected with the boiler, while the lower part is connected with the condenser.

405. **Two Important Attachments to the Engine.**—An opening is made in the top of the boiler, which is closed by a close-

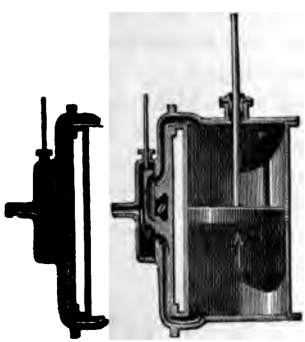

Fig. 224.—D-Valve and Cylinder.

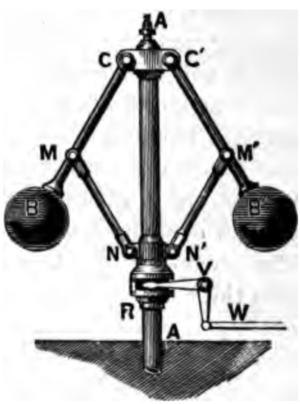

Fig. 225.—The Governor.

fitting plug of iron. This plug is held down by a lever-arm, at the end of which is a certain weight. When the pressure of the steam

becomes so great that there is danger of its bursting the boiler, it lifts this plug and escapes. This is called the *safety-valve*. A gauge is usually attached to boilers, which shows how great the pressure upon each square inch is at any time.

Fig. 225 shows a very ingenious invention by Watt, which automatically controls or governs the speed of the engine; hence it is called the *governor*. This is so attached to the engine that it revolves. If the engine runs too fast, the governor will revolve faster, and the two large balls will be thrown outward by centrifugal force. This raises R, which works a valve and shuts off a part of the supply of steam from the cylinder. If the engine runs too slow, there is less centrifugal force, and the balls fall, which lets more steam into the cylinder.

This governor is now giving place to a new device attached to the fly-wheel, which, as the centrifugal force increases, regulates the motion of the D-valve, shutting the steam from the cylinder early in the stroke, and making use of its *expansion* to drive the piston. This is found to be a saving of steam.

406. **The Locomotive.**—Fig. 226 is a section of a locomotive, showing its essential parts. In order to reach the smoke-stack the heated air and flames of the fire must pass through metal tubes. These tubes run directly through the boiler, and are very numerous, thus giving a very large heating surface. They are surrounded by the water in the boiler, and without these tubes it would be impossible to make steam fast enough to drive the locomotive at high speed. The cylinder is seen in front, and right above it is the D-valve, worked by the small rod which may be seen connecting it with the other machinery. The locomotive has no condenser, and is therefore a high-pressure engine. The steam escapes from the cylinder through the D-valve into the blast-pipe *v*, and thence up the smoke-stack. This greatly increases the draught of the fire, and causes the puffs of sound that we hear, and the puffs of steam that we see. Increasing the draught by letting the waste steam escape through the chimney, like the tubes in the boiler, was a very important invention, as it keeps up a hotter fire and thus generates steam faster.

Every one who uses this book is strongly urged to examine thoroughly engines of both sorts. Engineers will generally be willing to explain all their details.

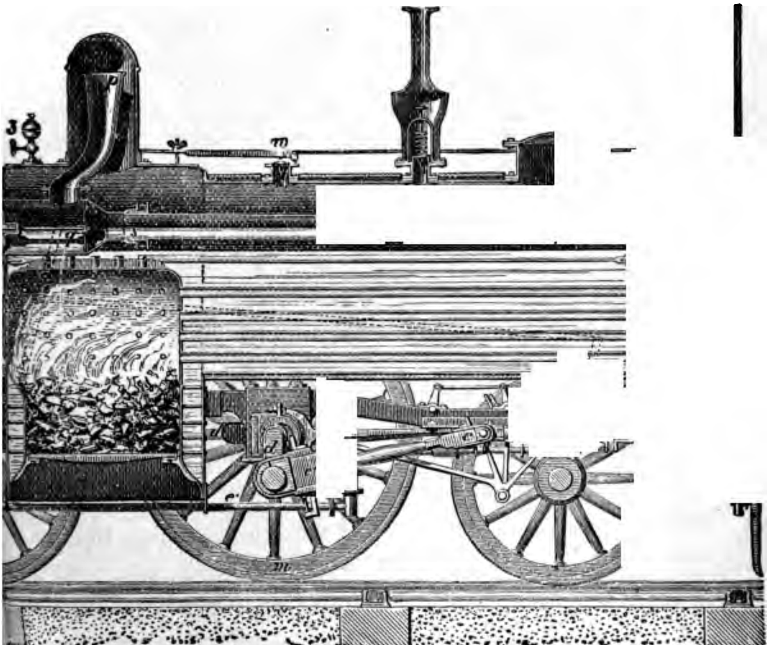

FIG. 226.—THE LOCOMOTIVE ENGINE.

407. How the Power of the Steam-Engine is estimated.— The power of an engine is usually estimated in *horse-power*. Watt estimated that a horse could raise 1000 tons one foot high in an hour.[1] An engine that can do that much work is a one horse-power engine; one that can lift 5000 tons one foot in an hour, or its equivalent, is a five horse-power engine. It is found that the steam produced from one cubic

[1] The raising of one ton 1000 feet in an hour, of half a ton 2000 feet in the same time, or any other equivalent, would be one horse-power.

foot of water will just about raise 1000 tons one foot high, so that an engine which can change five cubic feet of water into steam each hour is a five horse-power engine.

The student will not fail to notice that the steam-engine is a notable example of the conversion of energy. Heat is changed to mechanical force by the agency of steam and the machinery of the engine. Neither the steam nor the engine *produces* the power, and in the most efficient engine they really waste a great deal of it. But they are the best means yet found of converting on a large scale the molecular motion or force of the heat into mechanical motion. Nor will it be forgotten that the power to produce heat is in the coal, and was stored away by the sun's light and heat ages ago in the forests which produced our coal-beds. So it is really the sun's radiant energy shed upon the earth many thousands of years ago that is drawing all our railway-trains, driving all our steamships, and moving all our steam machinery to-day.

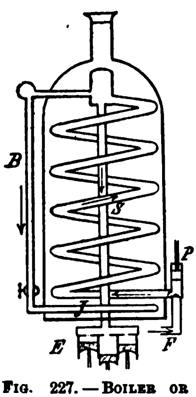

FIG. 227.—BOILER OR COIL OF NAPHTHA-ENGINE.

407*a*. **The Naphtha-Engine.**—In any steam-engine there is a necessary loss of much of the heat-energy of the fuel. It is only after the water is converted into steam that the heat, acting by *expanding the steam*, becomes effective in producing motion. The amount of heat used in converting the water into steam (Art. 374) is wasted as energy, and the high specific heat of water (Art. 361) makes it difficult to *raise it to the boiling-point*. The total loss of heat from these two sources is a large proportion of the heat-energy of the fuel.

In the naphtha-engine, naphtha is used instead of water in the boiler, and instead of coal as fuel. The specific heat of naphtha is much less than the specific heat of water, so that it becomes *hot more rapidly*; the boiling-point is lower, so that it *vaporizes sooner*; and the latent heat of the vapor is less, so that it *evaporates more rapidly*. These three facts combined give it a great advantage in efficiency over water. Part of the advantage is

lost, however, from the fact that naphtha vapor is heavier than steam,—that is, a pound of naphtha makes a smaller volume of vapor than a pound of water does. Naphtha is conveyed from the tank by the feed-pipe F (Fig. 227), and pumped into the boiler by the force-pump P. The boiler is a coil of pipe. Part of the vapor from the top of this coil is carried down by a pipe, B, and burned as fuel at the several jets in the pipe J. The remainder is carried by the pipe S down through the middle of the coil into the three-cylinder engine E. The condensed vapor is pumped back into the supply-tank and used over again. The naphtha-engine is used only where small power is required, large quantities of the fluid being difficult to handle with safety.

General Exercises.—1. Find the degree in the Centigrade scale which corresponds to 113° F., and that which corresponds to 140° F.

2. Find the degree in Fahrenheit's scale which corresponds to 15° C., and that which corresponds to 35° C.

3. Show that 30 cubic inches of air would expand to about 41 in passing from 0° C. to 100° C.

4. A gas measures 98 cubic inches at 185° F.: find what it will measure at 10° C. under the same pressure. *Ans.* 77, about.

5. If 50 cubic inches of air at 5° C. *below* 0° C. are raised to 15° C. under the same pressure, find the volume. *Ans.* 53.8, about.

6. Air which is known to have a volume of 100 cubic inches at 0° C. is found to have expanded to 120 cubic inches without any change of pressure: determine the temperature. *Ans.* 54.6°.

7. Find what weight of ice at 0° C. will be melted if put in a pound of water at 50° C. *Ans.* 10 ounces.

8. A mixture is made of 3 pounds of water at 12° C. with 3 pounds of water at 16° C.: find the temperature of the mixture. *Ans.* 14°.

9. A mixture is made of 4 pounds of water at 7° C. with 6 pounds of water at 12° C.: find the temperature of the mixture. *Ans.* 10°.

10. Unglazed pottery is sometimes used to hold water and to keep it cool: explain this.

11. Carbonic acid may be reduced to the liquid form by strong pressure; when the pressure is removed, the liquid returns to the state of gas, but some of it becomes *solid* carbonic acid: explain this.

12. A pound of iron at 99° C. is immersed in a pound of water at 0° C.: find how many degrees the temperature of the water will be raised, taking the specific heat of iron at .1. *Ans.* 9.

13. The air on a high mountain may be intensely cold although the sun is shining and no clouds exist: explain this.

14. The bulb of a mercurial thermometer is exposed to heat: will any difference be produced in the rate of rising of the mercury if the bulb is covered with silver foil?

15. Suppose we are provided with bars of copper, silver, gold, and platinum: explain how we must proceed to determine the conductive power of these metals.

16. A piece of platinum may be held in the hand while one end is red-hot, but a piece of copper of the same length under such circumstances will speedily burn the fingers: explain this.

17. A weight of a ton is lifted by a steam-engine to the height of 386 feet: find how many units of heat are required for this work. *Ans.* 1000.

18. A 68-pound cannon-ball strikes a target with a velocity of 1544 feet per second: supposing all the heat generated by the collision to be communicated to 68 pounds of water, how many degrees would the temperature of the water be raised? *Ans.* 2.

19. Show that to raise the temperature of a pound of iron from 0° C. to 100° C. an amount of heat is required which would lift about 7 tons of iron a foot high.

SUMMARY OF CHAPTER VII.

Heat is a vibratory motion which travels through solids by communication from particle to particle, but which travels through space as waves of ether.

The sun is *directly* the source of most of our heat, and *indirectly* the source of about all the remainder.

The stoppage of motion produces heat.

The heat required to raise the temperature of a mass of water 1 degree Fah. would be able to lift the same mass 772 feet high. This number is the mechanical equivalent of heat.

Thermometers measure sensible heat by the *expansion* of some material, generally mercury.

The unit of heat is the amount required to raise the temperature of 1 pound of water 1 degree Fah.

The specific heat of any substance is the number of units required to raise the temperature of 1 pound of it 1 degree Fah.

Heat expands nearly all substances; all *gases* uniformly and equally, *solids* and *liquids* unequally, and frequently not uniformly.

A gas at constant pressure increases its volume by $\frac{1}{273}$ of its volume at 0° C. for every degree of heat (C.) added, and decreases its volume the same amount for every degree taken from it.

A fall of temperature to —273° C. would reduce the volume of a gas to *nothing;* therefore this point, —273° C., or —459° Fah., is the *absolute zero of temperature.*

An expanding body does not rise in temperature as rapidly on being heated as the same body would if expansion were prevented.

Latent heat of fusion is the heat required to *melt* a solid,—*i.e.*, to keep the body in the liquid state. It does not *raise* the temperature of a body, and may *lower* it considerably,—*e.g.*, freezing-mixture.

Latent heat of evaporation is the heat required to convert a liquid into a vapor. It does not raise, and may lower the temperature of the substance.

It requires (Fah.) 144 units of heat to melt ice, and 967 to evaporate water. These on the Centigrade scale are 80 and 537.

Water expands on freezing.

A liquid boils when the pressure exerted on it is no greater than the tension of its vapor, and this varies with the temperature.

Radiant heat is reflected, refracted, diffused, etc., as radiant light is.

Dark dull surfaces radiate and absorb heat best. Bright polished surfaces reflect best.

Most liquids and gases are poor conductors of heat.

Our *sensation* of heat depends largely upon the conducting power of the substance which we touch.

Large masses of liquids and gases are heated by convection.

Heat is most largely utilized as a motive power, through the medium of steam and the steam-engine.

A low-pressure engine condenses its exhaust steam, thus saving warm water and gaining the pressure of the atmosphere.

A high-pressure engine forces its exhaust steam out into the air against atmospheric pressure, and loses what the other saves.

The naphtha-engine saves heat because of the low specific heat and low boiling-point of the liquid, and the low latent heat of its vapor.

CHAPTER VIII.

MAGNETISM.

408. **Magnets.**—A certain ore of iron,[1] frequently called loadstone, possesses the property of attracting metallic iron and steel quite strongly, and of attracting many other substances very slightly. A piece of iron, while near or in contact with a loadstone, possesses the same property, and a piece of steel placed in contact with the loadstone not only acquires this property, but retains it after having been withdrawn. The mountains surrounding the ancient city of Magnesia, in Asia Minor, were formerly famous for the production of loadstone, and from this city the name *magnet* has come to be applied to a piece of loadstone, or to any piece of iron or steel exhibiting the same power of attraction. When we have finished this chapter and the next, we shall have learned that there are many ways of imparting this interesting property to bars of iron and steel. At present we will consider magnetism, or this power of attraction, as a property communicated by the loadstone or "natural magnet." Good loadstones are small, inconvenient, and expensive, and bars of steel which have been stroked from end to end with the loadstone become magnets themselves, and are capable of transmitting the power to others. We shall, therefore, use steel magnets for our present experiments, and learn how to make them as we progress. A pair of such magnets, from three to six inches long, may be had

[1] An oxide of iron, usually of the composition Fe_3O_4. A large proportion of this ore of iron does not exhibit magnetic properties.

for a small sum, and will answer well for many of the following experiments.

409. **Poles of Magnets.**—Experiment 144.—Lay a magnet down on a bed of iron-filings, or in a box-lid containing a quantity of carpet-tacks or finishing-nails or "card-teeth." Be sure they are evenly distributed, so that all parts of the magnet may have equal access to them. Pick up the magnet, holding it horizontally by the middle. Notice that the small particles of iron are clustered at the *ends*, and that very few are to be found near the middle.

The attractive power of magnets resides at or very near the ends. These are termed the *poles* of the magnet. Every ordinary magnet has two poles.

410. **The Two Poles of a Magnet different in Kind.**—Experiment 145.—Touch two magnets together, end to end, and reverse one of them and then the other several times. Unless they are very different in size or strength, it will be found that in two positions they attract and adhere to *each other*, and in the remaining two positions they do not. Put temporary marks on the poles (if not already marked), so that they may be distinguished.

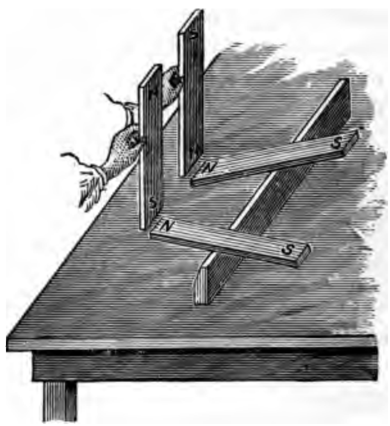

FIG. 228.—ACTION OF SIMILAR AND DISSIMILAR POLES.

Experiment 146.—Balance one of the magnets on the edge of a ruler. Bring each end of the other magnet from above quite near to each end of the balanced magnet. If the balancing is delicate enough, it will be found that the ends which in the previous experiment refused to attract each other, actually *repel* each other.

From these experiments it is evident that the two poles of a magnet, although capable of producing the same apparent effect in the iron-filings or tacks, are in some way different.

411. **Action of Similar and Dissimilar Poles.**—Experiment 147.—Hold two magnets of the same size and strength perpendicularly, one in each hand, and dip the lower end of each into a pile of

little nails, or something similar. Now bring the loaded magnets together, side by side. Reverse one of the magnets, and repeat the experiment. In one case the loads will remain adhering to the magnets after they are brought together, in the other case the loads will drop as soon as the magnets touch each other. Notice that the poles which are together when loads are *sustained* are those which were marked as *repelling* each other in Experiment 146, while those which are together when the loads are *dropped* are those which were marked as *attracting* each other.

It is evident that when the two poles unitedly sustain the double load, they must be *acting together*,—*i.e.*, they must be *similar*,—and that when the two poles which were strong separately refuse to hold any load unitedly, they must be acting *differently* or *oppositely*,—*i.e.*, they must be *dissimilar*. We are now ready to mark the poles of our magnets again, but not permanently yet. Put similar marks upon the poles that act together in sustaining the double load. From these experiments we derive the

Law of Action between Magnets:

Similar magnetic poles repel each other; dissimilar magnetic poles attract each other.

412. **Iron magnetized by Induction.**—**Experiment 148.**—With either pole of a magnet pick up a nail not too large to adhere firmly to the magnet and to stand out from it in any position. Touch the free end of this nail to another nail of the same size or smaller. It will be attracted. If the magnet is strong enough, the second nail will support (suspend) a third, this a fourth, and so on.

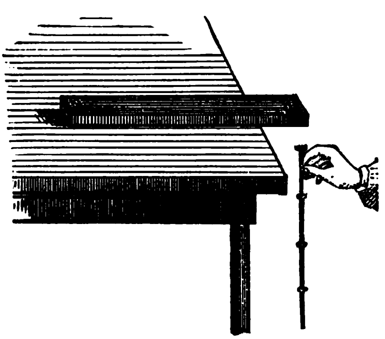

FIG. 229.—NAILS MAGNETIZED BY INDUCTION.

Experiment 149.—Touch the lower end of the chain of nails of the last experiment with that pole of the other magnet which is *dissimilar* to the pole from which the nails are hanging. It will adhere firmly. Form a chain again on a pole of one magnet, and approach its lower extremity with the *similar* pole of the other magnet. The nails will either be repelled or else they will let go their hold on one another and drop. If there are several nails in the chain they will probably all

drop, one by one, till the last one is reached, and it will be strongly repelled. Vary the experiment as follows: Rest the upper magnet on a table top, so that one pole will project beyond the edge of the table. Attach a chain of nails to this pole, and, when the magnet is nearly loaded, carefully pull the top nail downward a short distance from the magnet to which it adheres. If this is done carefully the nails will still adhere to one another, and exhibit the same properties of attraction and repulsion that they did while the upper nail was in contact with the magnet.

This experiment shows that there are two *dissimilar poles* in each nail while it is near to, or in contact with, the magnet; in fact, that each nail is then a *magnet* in itself. It is the steel magnet which, by its presence, *induces* the nails thus to act as magnets, and they are accordingly said to be magnetized by *induction*. Remember this word and the reason for its use, as it will be found frequently in this and the following chapter.

413. **Magnetization of Steel.**—Steel is magnetized by induction, as iron is, but it is very much slower in yielding to the magnet's influence. If one end of a needle be placed against a pole of a magnet it will exhibit very little attraction at its farther end. It requires repeated strokes across the end of a magnet fully to magnetize it, but when once magnetized, the steel, if good, retains its magnetism.

Experiment 150.—Lay an ordinary needle on one pole of a magnet, and, taking it by either end, draw it slowly across the magnet until it is torn loose from it. Lay it on the *other* pole of the magnet, take it by the *other* end, and draw it across as before. Repeat this a few times, being careful that the same end of the needle shall in each case *be pulled from the same end of the magnet.* The needle will be found to be permanently magnetic.

414. **Large Magnets.**—Large steel magnets may be made in a similar manner, except that the bar to be magnetized is generally laid on a flat table and one or two good magnets are drawn along it several times. The magnets which are thus used do not lose any of their own strength, though they impart the same amount to any number of bars. As a matter of fact, large steel magnets are generally made by contact with powerful electro-magnets. Further reference

to the subject must therefore be left till we reach electro-magnetism.

415. **Poles in the Particles of a Magnet.**—Experiment 151.—Magnetize two sewing-needles so that corresponding ends shall be similar poles, and test the strength of one with very small tacks. Cut it in half, and lay the pieces in a bed of the tacks. Each half will be a complete magnet with two poles. Compare the poles with the uncut needle. They will be found to correspond in *kind* with the poles to which they were nearest in the whole needle. Cut either half again and again, until the pieces are very small. In each case each piece will exhibit two poles, and *each pole will be found as strong as the original poles of the whole needle.*

We may make any number of short magnets by cutting up a longer one, the limit being reached only when the pieces become so small that we can no longer divide them with our cutting-tools. As we know the pieces of steel to be composed of infinitely smaller pieces than we can thus make, we may fairly conclude that *each particle* of a magnet possesses the poles and other essential properties of the whole magnet. This is also the case with the particles of a bar of iron which is rendered magnetic by the inductive influence of a magnet near it.

416. **Why a Bar is magnetized.**—We are now ready to state a little more clearly the theory of magnetism as exhibited in iron and steel bars. For the purpose of illustration, we will consider a bar to be a line of single particles placed end to end. When such a bar is brought sufficiently near the pole of a magnet, the particle nearest the magnet is *polarized* by induction; that is, it has two poles formed in it, one of which is attracted by the pole of the magnet, and the other repelled. The attracted pole is, of course, unlike the contiguous pole of the magnet, and the repelled pole is like it. This particle then acts by induction on the second particle, thus polarizing it; this acts on the third, the third on the fourth, and so on until all the particles are polarized, each one by the influence of the one next to it. When the particles are all thus polarized, each pole is engaged in attracting the pole next to it, *except those at the*

two extremities of the bar. These two, accordingly, are free to polarize and attract other pieces of iron, and they are therefore the poles of the magnet.

417. **Poles may be neutralized.**—If the two poles of a magnet be allowed to exert their attraction fully *on each other*, the magnet loses its power of attracting other bodies. This may be beautifully shown by the following:

Experiment 152.—Procure a piece of watch-spring about six inches long (your jeweller will willingly contribute it), and magnetize it by drawing it several times by alternate ends between the thumb and the respective poles of a magnet. Dip the poles of the magnet thus formed into small tacks. Carefully lift the load, and bring the poles together so as to make a circle of the spring. The load will drop, and any attempt to make it adhere to any part of the circle will be in vain if the spring has been evenly magnetized. In Experiment 147 the same effect was exhibited with the unlike poles of *two* magnets.

418. **The Attracted Body polarized.**—*Every particle of iron or steel attracted by a magnet is first polarized by the attracting magnet*, unless previously polarized by some other means. Fig. 230 suggests an experiment for verifying

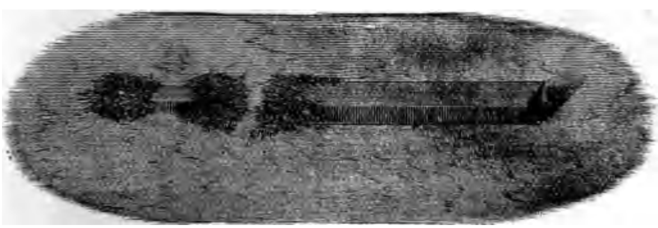

FIG. 230.—MAGNETIC INDUCTION.

this law. The smaller piece is soft iron. ("Soft iron" is the technical name for good wrought iron, and is used in distinction from steel.) If the piece of soft iron in the above figure were of the same size in cross-section as the magnet, and the two were placed in contact, end to end, there would no longer be any poles at the *junction*, but there would be one at *each end* of the compound bar.

419. Compound and Horseshoe Magnets.—As the attracted piece of iron is polarized, it is evident that the magnet would attract each end equally if it could reach them both at once. To accomplish this end, magnets are frequently bent into the form of a capital U. Such magnets are called "horseshoe" magnets. The action of a horseshoe magnet on a piece of soft iron is indicated in Fig. 231. The soft iron is called the *keeper*. When so constructed as to move pieces of machinery, it is called an *armature*. To obtain the best results from a large magnet of any shape, it must be made by fastening several smaller bars together, parallel with one another. This makes a compound magnet. Fig. 231 is a *compound horseshoe* magnet.

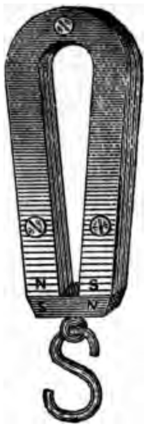

FIG. 231.—COMPOUND HORSESHOE MAGNET AND KEEPER.

420. Lines of Force.—**Experiment 153.**—Cut a groove in the face of a smooth board, so that a flat bar magnet may lie

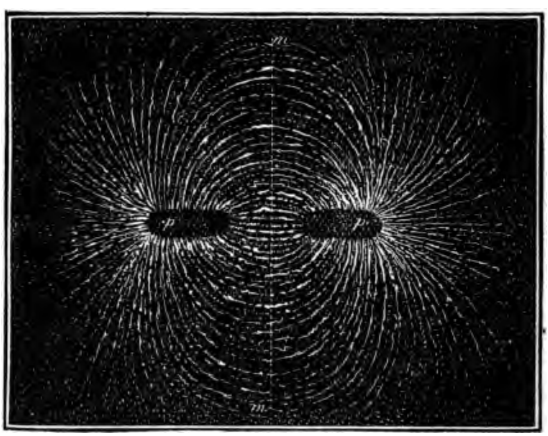

FIG. 232.—LINES OF MAGNETIC FORCE.

in it and have its upper side flush with the board. Place the magnet *in the groove*, cover it over with a smooth sheet of writing-paper, and

sift fine iron-filings over the paper. The filings plainly indicate the position of the magnet. Tap the board gently, and the filings will arrange themselves about as shown in Fig. 232. If the paper be placed on the poles of a horseshoe magnet, the filings will cluster more thickly.

These curves indicate the direction of what are known as the *lines of magnetic force.* The force of the magnet does not exist in the lines alone, it pervades the whole space surrounding the magnet. The particles of filings being magnetized arrange themselves in a definite *direction,* but not in a definite *place.* On repeatedly tapping the paper the rows of filings may be moved sidewise. If a small magnetized sewing-needle be stuck through a silk filament, it may be used to explore the whole field surrounding the magnet,—above, below, and in all oblique planes,—when it will invariably preserve a direction such as the lines of filings indicate.

421. **The Magnetic Field.**—The space thus influenced by a magnet is called the *magnetic field.* The intensity of this field of course varies as the strength of the magnet varies. The *unit strength of magnetic pole* is such as will repel a pole of the same name and strength, placed at a distance of one centimetre, with a force of one dyne. (Art. 58.) The expression "lines of force" is used to designate the strength of magnetic poles, or rather the intensity of magnetic force in any part of a field. One "line of force" in such sense is the intensity of magnetism in one square centimetre of magnetic field of unit strength, measured *across* the *direction* of the lines of force.

422. **Law of Magnetic Force.**—*Dissimilar magnetic poles attract each other, and similar magnetic poles repel each other with a force directly proportional to the product of their strengths, and inversely proportional to the square of the distance between them.*

423. **Directive Tendency of the Magnet.**—Experiment 154. —Make a stirrup of paper, and hang it to a convenient support by a

string that has no tendency to twist. Balance in the stirrup, one at a time, the two magnets which have been used in many of the previous experiments. After swinging backward and forward a few times, the magnets will each come to rest, pointing nearly *north and south.* It will be found that the ends of the two magnets which point in either of these directions are those which were marked as *similar* to each other after we had tried Experiment 147. We are now ready to mark the poles of our magnets permanently. Mark the pole which points northward "*N*," for north, or, rather, *north-pointing*, and mark the other end "*S*," for *south-pointing.*

All magnets tend to arrange themselves in nearly a north-and-south direction. This is because of magnetic property in the earth itself. Indeed, the whole earth may be considered as a vast magnet, having its magnetic poles near the geographical poles. How the magnetism of the earth is supposed to originate will be referred to in a subsequent chapter.

424. The Magnetic Needle.—A thin magnet, nicely balanced on a hard point, so that it may have great freedom of motion, is called a *magnetic needle.* Fig. 233 shows a common form.

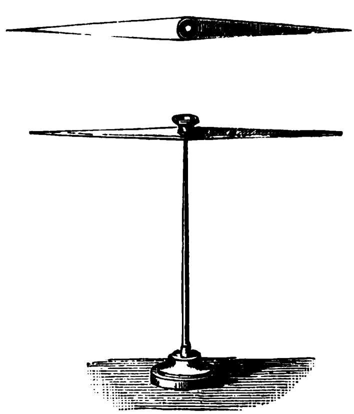

FIG. 233.—MAGNETIC NEEDLE.

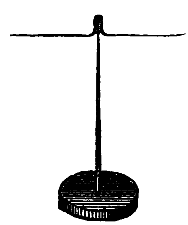

FIG. 234.—HOME-MADE NEEDLE.

Experiment 155.—To make a *very good* magnetic needle, take a piece of watch-spring six or eight inches long. Straighten it between

the thumb and finger. Then, holding the middle of it in the flame of a lamp, bend it as nearly "double" as possible without breaking. Bend the ends back into a line with each other, as shown in Fig. 234. Magnetize each end separately. Wind a waxed thread around the short bend that is left, and balance on a needle held upright in a flat cork or a card. A little filing or grinding will be necessary to make it balance. With a point filed on the north-pointing pole the needle is finished.

425. **The Compass.**—A magnetic needle, when fixed in a frame which is graduated in degrees and properly equipped with sights and levels, forms the surveyor's compass. When the needle carries a circular card with the "points" (north, south, east, west, etc.) marked on it, the arrangement is the essential feature of the *mariner's* compass.

426. **Magnetic Declination.**—Although the compass was used a thousand years before the Christian era, it has long been known that in most places the direction of the needle is not a true north-and-south line. The deviation from the meridian is called the *declination of the compass.* Navigators must know the declination for a given place and allow for it. If the declination in a given place were *constant*, the allowance could easily be made, but it is subject to many variations, some extending over long periods, some over shorter periods, some regular and some irregular. As the greatest amounts of variation occur regularly and take place slowly, the compass is still a valuable aid to navigators and explorers. The declination at Philadelphia in 1892 is about 5° west. At London it is about 17° west.

427. **Magnetic Dip.**—If a steel bar be exactly balanced in its centre of gravity so that it may move about its support in any direction, and then magnetized, it will not remain level, but (in the Northern hemisphere) the north-pointing pole will incline downward, pointing towards a place considerably below the horizon. This is known as the *dip* of the needle, and a needle so balanced and magnetized is a *dipping needle.* The dip is greater the nearer we approach to the magnetic poles of the earth. In the Southern hemisphere the south-pointing pole dips down.

The dipping needle indicates the direction of the *earth's lines of magnetic force.* Therefore, if we know the position of the magnetic poles of the earth, latitude may be roughly determined by means of a dipping needle. Humboldt[1] relates that on one occasion he successfully directed his vessel into the port of Callao, on the west coast of South America, by determining his latitude in this way.

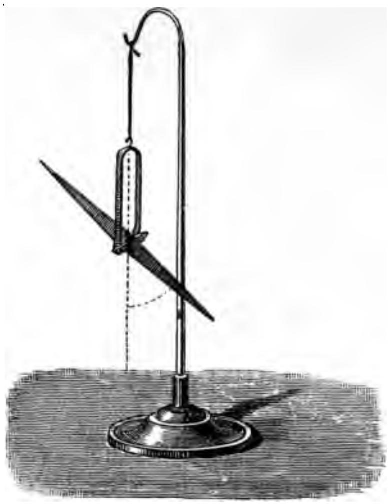

FIG. 235.—NEEDLE INDICATING BOTH DIRECTION AND DIP.

The dip of the needle at Philadelphia is about 75° with the horizon. The magnetic equator, or line of no dip, is somewhat irregular in shape, but crosses the equator in two points at an angle of about 12°, being that distance north of the equator in the Indian Ocean and the same distance south in Brazil. The north magnetic pole is about 10° north of the north shore of Hudson's Bay, and the south magnetic pole is in a corresponding position south of Australia.

428. **The nature** of the influence which magnets exert over bars of iron and steel to polarize their particles and make magnets of them, as explained in Art. 416, is little understood. We shall find in a succeeding chapter, however, that there is a close connection between magnetic phenomena and the existence of electric currents.

(The summary of this chapter is given with that of Chapter IX.)

[1] Alexander von Humboldt, German, 1769–1859. An illustrious traveller, and an eminent scholar in many branches of learning. An *authority* on most scientific subjects.

CHAPTER IX.

ELECTRICITY.

I.—STATIC ELECTRICITY.

429. **Electrical Phenomena.**—It was known to the ancients that amber rubbed with some soft material possessed the power of attracting light bodies. It has since been discovered that many other substances exhibit the same property. The Greek name of amber is *elektron;* hence the name *electricity* came to be applied to the force thus developed, whether in amber or in any other substance. A gutta-percha comb, after being drawn through dry hair, in cool, dry weather, will pick up small tufts of cotton, pieces of paper, scraps of corn-stalk-pith, or any similar light substance. A sheet of thin paper rubbed with an eraser adheres tightly to the sheet under it, or to a wall. The force which holds these bodies together is electricity.

Note.—**Apparatus Needed.**—For the fundamental experiments in static or frictional electricity the pupil should have two *glass rods* or heavy tubes about 15 inches long and ¾ of an inch or more in diameter; two smaller rods of *shellac*, sealing-wax, or gutta-percha; a silk handkerchief or pad; a cat's skin tanned with the fur on; a lot of pith balls of about ½ inch in diameter, made by cutting the dried pith of corn-stalks into shape with a sharp knife; a spool of silk and one of thread; a few bottles and other glass vessels; a supply of corks, pins, needles, wax.

For electrical testing, a *proof-plane* and an *electroscope* are needed. The proof-plane is a circular piece of tin 2 inches in diameter, with a glass handle standing perpendicularly in the middle, stuck on with wax. The electroscope is shown in Fig. 238, and is easily made. A piece of gold-leaf 4 inches by ½ inch is hung in the wire loop. The wire is run through the cork, and has a tin dish soldered to its upper end. Dry the bottle *very thoroughly*, and insert the cork with its wire and gold-leaf.

For further experiments use will be found for an electrical machine, a Leyden jar, a discharger, an insulating stool, and many other things described or mentioned as we proceed, or suggested to the students themselves as they study the subject.

All apparatus must be *dry*, which is insured by having it *warmer than the outside air*. Much glass contains such metallic substances as render it very poor for electrical experiments. If apparatus otherwise properly constructed will *not* do as it should, try new glass.

Experiments in frictional electricity succeed best in *crisp winter weather*, when the atmosphere contains but little moisture. In summer weather it is sometimes difficult or impossible to produce electrical excitement with simple apparatus.

430. **Electrical Attraction.**—**Experiment 156.**—Grasp a glass rod near one end and rub it briskly with the silk. A crackling noise and a sensation as of cobwebs on holding the rod near the face indicate that it is electrified. Hold it near a light rubber ball placed on a smooth table. The ball will be attracted, and will follow the rod around the table several times. A round collar-box or a hoop of any light material will answer equally well. Rub a rod of shellac with the flannel and present it to the ball or the hoop. The same result will follow.

431. **Attraction and Repulsion.**—**Experiment 157.**—Make a "wire loop" (such as is shown in Fig. 236) of sufficient size to hold the glass and shellac rods. Suspend it by a silk thread or narrow ribbon to a convenient support. Rest in it one of the glass rods. Rub the other rod with the silk, and bring it near the suspended rod. There will be an *attraction.* Repeat the experiment, but this time rub the first rod before placing it in the loop. On presenting the other glass rod, freshly rubbed, there will be a *repulsion.*

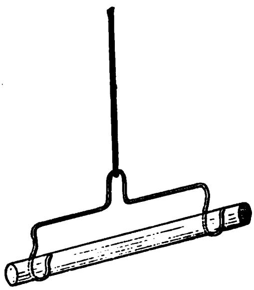

FIG. 236.—WIRE LOOP.

Follow the same course with the rods of shellac rubbed with flannel. They will act in the same way. Remove the electrical excitement from the surface of one of the shellac rods by drawing it through the hand. Place it in the loop and present a freshly-rubbed glass rod. There will be attraction. Rub the shellac rod and again present the rubbed glass. There will still be attraction.

432. **Positive and Negative Electricity.**—The last experiment shows that the two electrified bodies, though behaving similarly towards the unelectrified indicator, are different manifestations of the same force. It recalls the experiment which proved the difference between the two poles of a magnet. Here, however, both ends of the electrified body are similar. The *electric states of the two bodies*, the glass and the shellac, are *dissimilar* throughout. For distinction, the electric force developed on smooth glass by rubbing it with silk is called *positive electricity*, and that developed on shellac by rubbing it with flannel is called *negative electricity*. Electricity may be produced by friction between any two

different substances, and, as we shall see hereafter, in many other ways; but it is always positive or negative. Positive electricity is frequently designated by the + sign, and negative by the — sign.

433. **Law of Attraction and Repulsion.**—Experiment 157 will have suggested the following law: *The two kinds of electricity attract each other, but each is self-repellent.*

No reason has been discovered why one body should exhibit positive electricity and another negative. When a substance whose nature is unknown is electrified, it must be tested by one whose electricity is known. To test a body, ascertain whether glass or shellac, electrified, *repels* it.

434. **To charge a Body.**—**Experiment 158.**—To each end of a silk thread two feet long attach a pith ball, and suspend the silk by the middle. Rub a glass rod with silk and touch it to the balls as they hang together. They will now repel each other and stand apart for a considerable time.

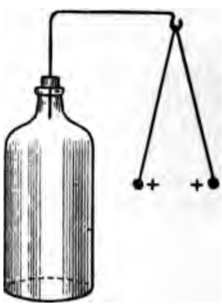

FIG. 237.—ELECTRICAL REPULSION.

This experiment shows that electricity passes from one body to another. Each ball has taken some of the positive electricity from the glass, and the two, being similarly electrified, repel each other. A body which has taken some electricity from another is said to be *charged.* An *excited* body is one electrified by friction.

435. **Positive and Negative Neutralize each other.**—If the glass and shellac, both electrified, be rubbed or rolled thoroughly over each other, each will lose the principal part of its charge. This leads to the conclusion that each is capable of destroying the electrical state of the other. If the quantities of positive and negative on the glass and shellac respectively were equal, there will be *no charge* on either after their contact. In this respect the two electricities are like positive and negative algebraic quantities.

436. **The two rubbed Bodies differently Electrified.**—When bodies are electrified by rubbing, the *rubbed body* exhibits one kind of electricity, and the *rubber* the *other* kind. Try the following:

Experiment 159.—Rub a glass rod with a silk pad (holding the pad in a piece of sheet-rubber,—*e.g.*, the top of an old overshoe), and present the pad to some light pieces of feather or something of the kind. There will be an attraction, showing that the pad is electrified. Rub the rod again, and suspend it as in Experiment 157. The pad and the rod will attract each other, showing that they are differently electrified.

As stated above, any two substances rubbed together develop electricity. Whether any one substance exhibits positive or negative depends upon what it is rubbed with. Glass has been spoken of as yielding positive electricity. It does so when rubbed with silk, buckskin, or an amalgam (mercury, zinc, and tin). When rubbed with flannel or fur, it is negative.

437. **Electricity is not** in any sense a *substance*, as would be indicated by some of the expressions used in speaking of it. It is rather a state of strain which the body, or more likely the air, or possibly the *ether* surrounding the particles of the body, exhibits, as an equivalent of the energy applied to produce it. As, however, we speak of certain well-proved ethereal vibrations as "light," of others as "heat," and so on, so we call this undemonstrated action "electricity." *What it consists in* is left to the future, possibly the *near* future.

438. **Conductors and Insulators.**—If an electrified rod be touched to one end of a metal bar, an indicator at the other end shows that the electric energy is immediately felt there. If the same experiment be tried with a glass bar, the electricity does not manifest itself to any appreciable extent at the farther end. Substances which readily transmit electricity are called *conductors*. The metals, charcoal, wood, water, hemp, and animal bodies are conductors. Two or more bodies connected by conductors are said to be in *electrical connection*.

Substances which transmit electricity feebly, or not at all, are called *insulators*, and a body *in contact with nothing but insulators* is said to be *insulated*. Dry air, shellac, rosin,

beeswax, glass, india-rubber, and silk are among the most common insulators. As the human body is a conductor, it is evident that we should handle all electrified bodies by means of insulating handles if we would have them retain their electrical condition. Particles of dust and moisture which may collect on insulators have some power of conduction: hence the caution to keep all electrical apparatus while in use *clean* and *warm*.

439. **Electrical Induction.**—As a magnet may communicate its power of attraction to a piece of iron at a short distance from it, so an electrified body may induce electrical phenomena in another body without touching it.

Experiment 160.—Bring the electrified glass or shellac rod near the knob or plate of the gold-leaf electroscope. (Art. 429.) As it approaches the leaves will diverge, and as it recedes the leaves will come together. Repeat several times in succession.

The gold-leaves in this experiment are similarly electrified by induction and repel each other. The condition of different parts of the apparatus is shown by the signs in the figure, the negative being attracted by the positive in the glass rod, and the positive being repelled.

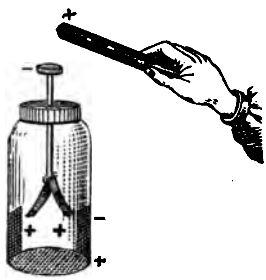

FIG. 238.—GOLD-LEAF ELECTROSCOPE.

Experiment 161.—Touch the proof-plane (Art. 429) to an excited glass rod, and then to the top of the gold-leaf electroscope. The leaves become charged, and remain diverging after the proof-plane is withdrawn. Carry a second charge from the glass to the gold-leaves. They diverge more widely. While they are still divergent, carry to them with the proof-plane a charge from excited shellac. The negative electricity neutralizes some or all of the positive in the leaves, and they fall towards each other.

440. **To Test the Kind of Electricity.**—Experiment 161 indicates how we are to test the kind of electricity on any excited surface. Diverge the gold-leaves with a known kind. While they are still divergent, the contact of a body *similarly* electrified produces *more* divergence, and the contact of a body *oppositely* electrified produces less divergence.

441. Body electrified by Induction.—Experiment 162.—Procure or make a cylinder whose length is about four times its diameter. Eight and two inches are very convenient dimensions for these experiments, though very much smaller will do, and very much larger are better when we have much electricity. The ends must be convex, as shown in Fig. 239. The outside of the cylinder, ends and all, must be of some conducting material. Turned wood covered with tin-foil answers admirably. A hollow tin can with round ends would be good. An egg, an apple, a croquet-ball, would do. This is an *induction cylinder*. Support it on glass or wax, or hang it by silk. Hold an excited rod near one end. *While it is held there*, touch first one end and then the other of the induction cylinder with the proof-plane, and test each with the gold-leaves. The end next to the excited rod will be found in the electrical state *opposite* to that of the rod, and the farther end will be found *similar* to the rod. Try the middle of the cylinder. It will be found neutral.

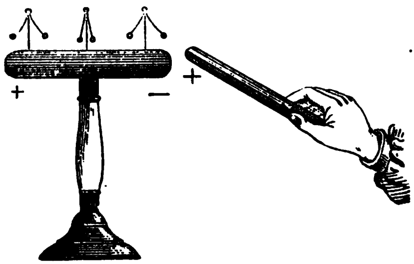

FIG. 239.—INDUCTION CYLINDER.

442. Cause of Attraction by an Electrified Body.—All bodies electrified by induction show the above result. The electrifying body attracts the opposite and repels the similar electricity, in accordance with Art. 433. This brings us to an important principle of electrical attraction,—viz., *a body attracted by an electrified surface is first electrified by induction, and the apparent attraction of the bodies is really the attraction of the opposite kinds of electricity.*

443. Induction due to Ether.—Until recently it was thought that electrical induction represented *influence at a distance*, rather than *action through a medium*. It is now, however, nearly certainly proved that induction is the action of electricity through the same *ether* that carries light-waves. It acts through long distances, it travels with the velocity of light, it exhibits phenomena of interference seen only in waves, and in many other ways its behavior conforms to that of wave-motion in a highly elastic medium.

444. Why a Body is charged.—The body which electrifies another by induction does not thereby lose any of its *charge*; but if a body which is electrified be brought into

contact with one which is not, the electrified body does lose some of its electricity. Suppose the first body to be positively electrified. Part of the positive electricity combines with the negative which has accumulated on the nearest part of the other body. The farther extremity of the second body remains positively electrified by repulsion. When the electrifying body is withdrawn, this positive electricity disposes itself symmetrically over the surface of the body, and the body is *charged.*

445. **Insulators easily charged.**—It will have been noticed by the pupil, before reaching this point, that the substances upon which we develop electricity are insulators. This is largely because glass, shellac, etc., are easily excited, but partly because the very fact of their being insulators enables them to *retain* the charge which is developed on their surface. When any point of a charged *conductor* is placed in electrical connection with another conductor of very large size (the earth, for example), the whole charge passes off, and the body is said to be discharged. In order to discharge a charged *insulator*, all parts of its surface must be placed in electrical connection with a large conductor, or with a conductor *oppositely* electrified.

446. **The Charge on the Surface.**—Delicate experiments have shown that the *charge lies wholly on the surface of a body which is a conductor.* A hollow sphere of the thinnest metal will contain as heavy a charge as a solid ball of the same size, and so with a conductor of any external shape.

This may be experimentally proved by trying the inside and outside of a hollow charged conductor with the proof-plane and electroscope. Faraday[1] tried the experiment on a much larger scale. He built a box

[1] Michael Faraday, English, 1791–1867, — one of the most noted philosophers of this century. His researches, abundant and striking in many branches of chemistry and physics, were especially so in electricity and magnetism. He discovered the principle which is applied in the present method of producing the current for electric lights, and many other facts and methods of interest.

of wood twelve feet in each dimension, and covered it over with copper wires and tin-foil. This was connected with a powerful machine; and then (in his own words) "I went into the cube and lived in it, using lighted candles, electrometers, and all other tests of electrical states. I could not find the least influence upon them, or indication of anything particular given by them, though all the time the outside of the cube was powerfully charged, and large sparks and brushes were darting off from every part of its outer surface."

So persistently does the charge keep to the outside that if a charged conductor be turned inside out any number of times without discharging it, the electricity shifts from one surface to the other, and is always found on that surface which for the time being is outside. Faraday devised for this experiment a linen bag, kept open by a ring at the mouth and turned either way by silk strings made fast to the bottom. (See Fig. 240.)

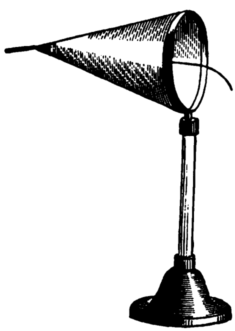

FIG. 240.—FARADAY'S BAG.

FIG. 241.—WIRE CYLINDER.

A small wire cylinder (Fig. 241) will protect a body placed inside from electric influence. Both the wire cylinder and the linen bag, tested with the proof-plane and electroscope, show the charge, if any, entirely on the outside surface.

447. Density of Charge on Different Parts of a Surface.— The charge of a *spherical* conductor is distributed equally over the surface, if not influenced by other charged bodies near it. In other words, there are equal quantities of electricity on equal areas of the surface, or the *density of the charge* is uniform. The density on the surface of any body

other than a sphere varies. On a cylinder with round ends, it is greatest at the extremities; on an egg or a pear, it is greatest at the smaller end; on a circular plate, it is greatest at the circumference; on a square disk, at the corners; and, in general, it is greatest at the most sharply-projecting parts of the body, sharp points and edges exhibiting the greatest density.

448. **Action of Points.**—The result of the great density of charge at any sharp *point* connected with a conductor is to allow the charge to escape rapidly. This is due to the *electrification of the particles of air, which become carriers and are repelled from the charged point.* The effect is the same on a body electrified by induction.

Experiment 163.—Touch an insulated cylinder (see Fig. 239) with an electrified body. While the balls are divergent, point a needle or an open penknife towards it. The balls will fall together, and remain so after the point is withdrawn.

Supposing the cylinder charged with positive electricity, when the hand is held near it a negative charge is induced in the hand. The effect of the point is to allow the negative from the hand to pass across by the air-carriers, and neutralize the cylinder. (See Experiment 167.)

449. **Unit Quantity of Electricity.**—Electricity may be measured for quantity, as heat and other agents may. The quantity of electricity is estimated by the strength of attraction and repulsion exerted by it at a definite distance. The *unit quantity* is that which will *repel* an equal quantity of the *same sign* placed at a distance of *one centimetre* with a force of *one dyne.* It is equally true that the unit quantity attracts the unity quantity of the opposite kind with the same force. This is in air.

450. **Law of Quantity and Distance.**—*The attraction or repulsion between two electric charges is directly proportional to the product of the charges, and inversely proportional to the square of the distance between them.*

451. **Potential.**—The term "potential" used as a noun means power or possibility. Electrical potential is the power or possibility of doing electrical work; but as the

use of the term potential is almost entirely restricted to electrical potential, this is spoken of simply as "potential." The potential of a body, then, is its ability to display electrical energy. It is only when two bodies *differ in potential* that electricity may pass from one to the other, and thus do work.

There is a difference of potential between a body positively electrified and a body negatively electrified, also between a body either positively or negatively electrified and an *un*electrified body. A difference of potential may exist between two bodies having charges of the same sign, one having a greater charge than the other. A body charged with positive electricity has a + potential. A body negatively charged has a — potential. The potential of the earth is assumed to be 0.

The electrostatic potential of a conductor is the same at all points of its surface. This is not necessarily the case with a non-conductor. When two bodies of different potential are connected by a conductor, there is a flow of electricity from one to the other until they are of the same potential.

Do not confound potential and density. The density varies on different parts of a conductor, the potential does not. In the induction-cylinder of Fig. 239 there is some density of charge at each end, but none in the middle. This is shown by the pith balls. There cannot be difference of potential, or the electricity would pass from one end to the other and restore equilibrium. Though we take away by conduction some of the + electricity from the + end, and thereby do some work, the conductor would be left negatively charged and the work would be *un*done in passing the + charge back to restore it to its original potential, 0.

An *un*electrified body has no potential. The earth, on account of its size, quickly distributes and combines positive and negative electricity coming to it from whatever source, hence it is taken at zero, as above stated. Positive electricity is considered to be of *higher*, and negative of *lower*, potential than the earth. Earth connections are frequently made for the purpose of getting rid of a charge either positive or negative.

452. The Electric Spark.—Electricity passes through conductors quietly and without visible effect. Sometimes a charge of high potential will rend apart the molecules of a non-conductor, and thus force a passage. This produces a spark. When masses of *air* are thus torn apart, the spark is sometimes long and brilliant.

453. Electrical Machines.—We have now learned all the principles involved in the construction of electrical machines, and, as many experiments succeed best when an electrical machine is used, we shall describe a few common forms.

454. The Plate Electrical Machine.—The circular glass plate G (Fig. 242) is clamped to the axle and turned by the handle. The

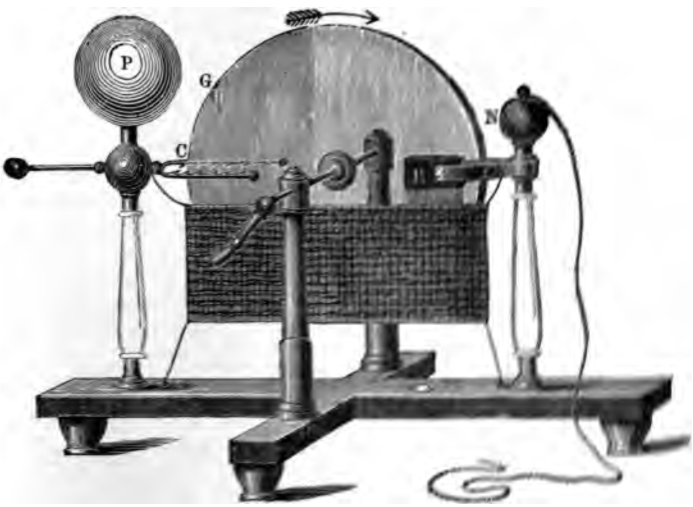

FIG. 242.—PLATE ELECTRICAL MACHINE.

arrow shows the direction of rotation. Two rubbers at R are pressed by springs against opposite sides of the plate. These springs are connected with the ball N, which is insulated on glass and forms the *negative* conductor. On the opposite side of the plate is the positive or *prime* conductor P, also on an insulating support. The combs C are brass points in electrical connection with the prime conductor. The rubbers may be silk, or chamois-skin coated with "electrical amalgam."

(Art. 436.) (The rubbers have tallow spread on the face, and the amalgam is spread evenly over this.)

When the handle is turned, the friction develops positive electricity on the glass and negative on the rubbers. This *charges* the negative conductor. When the plate has turned half-way round, its positive charge acts inductively (Art. 441) on the prime conductor, repelling positive to the left-hand extremity, and attracting negative to the combs C. This negative is taken by the air-carriers to the plate, thus neutralizing its positive charge, and leaving a charge of positive on P. This action is continuous while the plate turns, the difference of potential between the + and — conductors rising to its practical maximum. Any conductor brought near P receives a spark of positive electricity, and one brought near N receives a negative spark. If P and N be connected by a wire or chain, the electricity flows from P to N; the two are thereby kept at the same potential, and the action is absolutely continuous. The upper half of the plate is always *neutral*, the lower half *positive*.

If a chain attached to the negative conductor be dropped on the floor as shown, or better, be attached to a water-pipe, that conductor is "grounded," and we may now draw much longer sparks from P. The machine is capable of producing a certain *difference of potential* between P and N. If N is insulated, it *holds* the — charge, and the difference in potential between P and N is half — and half +. When, however, N is grounded, positive flows from the earth and raises the potential of N to 0,—that of the earth. The same difference of potential between P and N is now *all positive.*

455. The Cylinder Machine.—Fig. 243 represents a cylinder machine, which is much less expensive than a plate machine. Any school-boy may make one. A large bottle (one that would hold from one to four quarts) will answer for the cylinder. A glass rod, G, supports the prime conductor, C. This may be of wood, covered with tin-foil. Let the tin-foil extend so far as to the pin-points, P. R is the rubber, made of leather, or chamois, or silk, stuffed with wool. A silk apron, S, attached to the rubber and extending over the cylinder, adds to the certainty of its working. The rest of the machine is of dry wood.

456. Induction Machines.—The two forms of machine described above are simple in operation and easily understood. Until recently they were the dependence as sources of static electricity, which, being developed in them as on

rods of glass, etc., by friction, came to be called "frictional electricity." The frictional machines are now generally

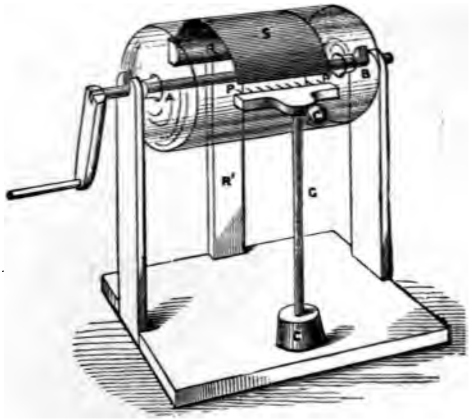

FIG. 243.—CYLINDER ELECTRICAL MACHINE.

superseded by "induction" machines. The elementary principle of an induction machine may be understood from

457. The Electrophorus.—This consists of a plate of resin or sulphur made by pouring the melted material into a round tin vessel, half an inch or more in depth. The *lid* may be made of wood with rounded edges, and covered with tin-foil. It is rather smaller than the plate, and has a handle of glass or vulcanite. A tinsmith can supply the materials for making one.

To operate it the plate is stroked with fur. The lid is then placed on it. The plate being a non-conductor, and not absolutely smooth, the lid touches it in but few points, and is to be considered simply as *very near to it.* The lid is then electrified by induction, as shown in Fig. 244, *a.* If it be now lifted by the handle, the positive and negative reunite, and it is found not charged. If, however, while the lid is on, the operator touch it with his finger, as shown in Fig. 245, the negative finds a way of escape, or neutralization. If now the finger be removed and the lid lifted by the handle, the positive distributes itself over the surface as a *charge.* (Fig. 244, *b.*) This charge may be communicated to any conductor as a spark. The lid may be again placed on the resin, touched with the finger, raised and discharged; and this may be repeated a large number of times without recharging the plate.

Furthermore, the charge on the lid *each time* is nearly as great in quantity as the original charge on the resin.

The positive electricity held to the lower surface of the plate by the attraction of the resin is said to be *bound*, the

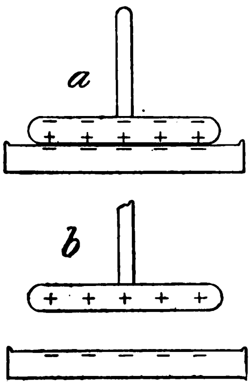

Fig. 244.—Action of Electrophorus.

Fig. 245.—The Electrophorus.

repelled negative is *free*. This distinction will be again referred to when describing condensers.

458. **The Toepler-Holtz Machine.**—This is an effective type of induction machine now rapidly coming into use. Fig. 246 shows the triple-plate Toepler-Holtz machine, constructed by James W. Queen & Co., of Philadelphia. The large circular glass plate in the middle is stationary. The two smaller plates, one each side of the stationary plate, are put into rapid rotation in the direction shown by the arrow on the driving-wheel. The stationary plate has glued to it two large paper "inductors," II. On the front revolving plate are six metallic buttons, C, called "carriers." The rod R, which extends across the plate, has a comb at each end and also a metallic brush. The bent rods or "collectors" A connect with the inductors, and support in front similar metallic brushes.

When the machine is standing there is a slight difference of potential between the two inductors. Suppose the right-hand inductor to be negative and the other positive. We will consider the effect first on the carriers and inductors. The carriers are polarized during their *passage* over the inductor, the attracted charges being bound, and the

repelled charges free, as in the lid of the electrophorus. As they pass the brushes on R, the free charges are conducted off, and being of opposite sign they unite in the rod. The carriers thus pass *charged* from one inductor to the other. These charges are taken off by the collectors A and added to the charges of the respective inductors, which thus soon become heavily charged, and remain so while the machine is in operation, and for some time thereafter.

The inductors now act strongly on the revolving plates, inducing charges similar to their own on the outside of the plates. These charges

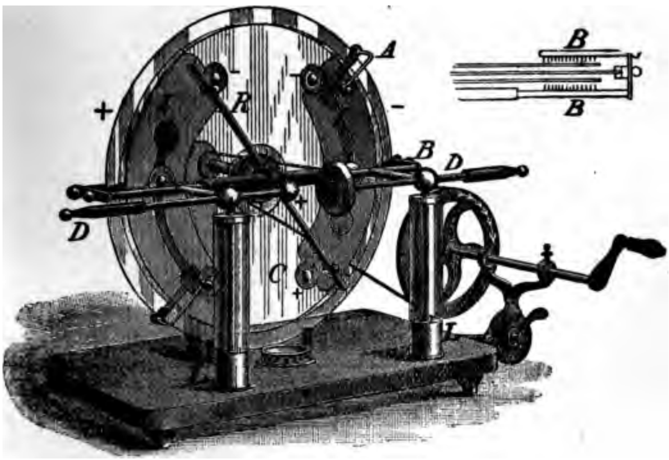

FIG. 246.—TRIPLE-PLATE TOEPLER-HOLTZ ELECTRICAL MACHINE.

are neutralized by a brush discharge from the "combs" BB, shown in plan separate from the machine. This leaves the sliding-rods DD charged, just as the prime conductor of the plate electrical machine was left charged with positive by having its negative withdrawn. These, of course, are charged differently. If the right-hand inductor is negative, the discharge from B is positive, and the right-hand sliding-rod, D, is negative. The corresponding parts of the machine on opposite sides of the revolving axis are always opposite in sign. The two revolving plates are alike in sign in corresponding parts. A shower of sparks passes between the knobs on DD while the machine is turned, or the discharge may take place as a current through a wire. The Leyden jars LL increase the effectiveness of the spark. The right-hand discharging-rod is furnished with a disk-shaped knob having a rubber

face, which acts as an additional condenser (Art. 461), and thus further increases the energy of the discharge.

459. Many other forms of electrical machine have been devised. The Armstrong hydro-electric, or steam electrical machine, develops prodigious quantities of electricity by the escape of high-pressure steam from a boiler, through a specially devised jet, and collects it on a conductor through the action of a row of points set in the escaping steam.

460. Experiments with Electrical Machine.—To experiment in attraction and repulsion with an electrical machine, ground the negative ball and connect with the positive. Consider the table on which the apparatus is placed as making connection between positive and negative. Remove the condensers of a Holtz machine for these experiments.

Experiment 164.—Hang from the end of the prime conductor a round metal plate by the centre. Hold under it a similar plate on which are placed a few paper or pith images. When the machine is operated, the images will dance vigorously between the plates. Vary this experiment by supporting the lower plate on glass. Explain both phenomena.

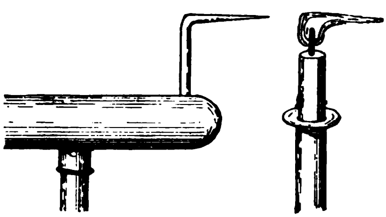

FIG. 247.—ELECTRICAL DISCHARGE FROM POINT.

FIG. 248.—ELECTRICAL CHIME.

Experiment 165.—Suspend three bells, as shown in Fig. 248. Any bells will do. Suspend those at the end by conductors, and the middle one by silk. Suspend two little metal clappers by silk. Let a chain or wire drop from the middle bell to the floor. Operate the machine and hear the result.

Experiment 166.—Suspend a light figure of a boy in a silk swing a foot long. Arrange the swing so that the figure will hang midway between the prime conductor and a metal knob, or a knuckle held a few inches distant. Let the machine be turned. Devise a see-saw, a *pump-handle*, or a man sawing wood to be operated by electricity.

Experiment 167.—Grind to a point a stout wire six inches long. Bend the wire at right angles near the point. Insert the other end into the hole in the prime conductor. When the machine is worked, hold a lighted candle at the point of the wire. The flame is blown from the point, as in Fig. 247. (See Art. 448.)

Experiment 168.—Stick four or six of these sharpened and bent wires into a cork, so that they will all be in the same plane and balance horizontally. Insert a thimble or a lamp-extinguisher in the cork, and push the wires in against it. Balance on a straight sharp wire which stands in the hole in the prime conductor. The points and the molecules of air *repel each other*, causing the "flyer" to revolve. (Fig. 249.)

Experiment 169.—Make a very small hole in the bottom of a tomato-can. Partly fill the can with water, and hang on the prime conductor by a wire. If the water drops slowly from the hole before the machine is operated, it will be forced out in a diverging spray on the turning of the handle.

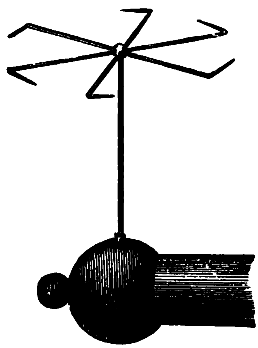

FIG. 249.—ELECTRICAL FLYER.

461. Condensers.—A conductor of given size and shape, placed remote from other conductors, may be made to hold a *certain quantity* only of electricity. When, however, a charged conductor is brought near to another conductor, an inductive action is set up between them, and each increases the capacity of the other. Suppose the conductors to be two sheets of tin-foil, pasted to opposite sides of a piece of glass. Every unit of positive electricity communicated to one sheet binds a unit of negative on the other sheet, and repels a unit of positive, as in the electrophorus, the *signs* only being different. If this repelled unit of positive be carried to earth, the negative unit binds the original positive unit. The first sheet is now in condition to receive an additional unit, and the operation of repelling and binding is repeated. This may go on till both sheets are heavily charged. Neither sheet alone will give any electricity to a neutral body. Any arrangement of this kind—*i.e.*, two conductors of large surface separated by a thin insulating medium—is a *condenser*.

462. The Leyden Jar.—The most common form of condenser is the Leyden jar, so called because the discovery which led to its construction was made at Leyden about the middle of last century. As bought of an instrument-maker, it consists of a glass jar (see Fig. 250) with coatings of tin-foil inside and out, covering the bottom, and

FIG. 250.—DISCHARGING LEYDEN JAR.

the sides about two-thirds of the way to the top. A rod, piercing the cork, ends above in a ball or ring, and below in a chain or wire reaching to the bottom of the jar. To charge the jar, take it in one hand by the outside coating. Present the knob to the prime conductor. Sparks of positive electricity pass from the conductor to the ball, and so to the inside coating. Every unit of positive electricity passing to the inside coating attracts an equal quantity of negative to the outside coating through the hand and body of the operator, which make an earth connection. Thus, by the passage of positive from the machine to the inside and the inductive accumulating of negative on the outside, the jar soon becomes *charged*.

463. The Discharge.—Any conductor made to reach from *the outside* coating to the knob *discharges* the jar. In the

figure, the operator is using a "jointed discharger." This carries the whole charge at once, a spark jumps from ball to ball, and we have an instantaneous disruptive discharge. If the jar is heavily charged, the spark may pass directly from the outside coating to the knob, or even through the glass.

If a body capable of taking a small charge of electricity is suspended by a silk thread between two conductors which are in electrical connection with the two coats of the jar, it will carry successive charges of positive to the outside coat, and of negative to the inside coat, until the two are neutralized in both. The little clapper shown in Fig. 251 will swing between the bells and keep up a chime for an hour, under favorable conditions.

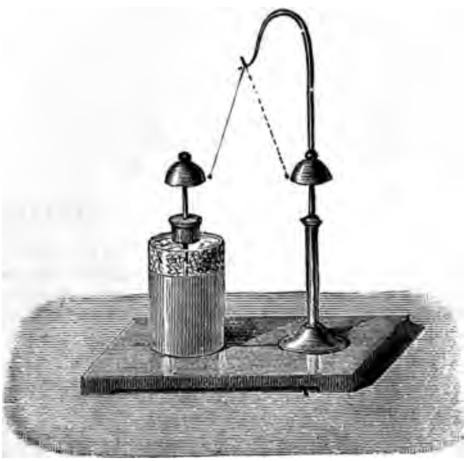

FIG. 251.—SLOW DISCHARGE.

464. **The Shock.**—When the discharge of a Leyden jar takes place through a conductor which is not very good, the human body, for instance, it produces a "shock" of more or less severity.

An accidental shock led to the invention of the Leyden jar. A pupil of an experimenter in Leyden was "storing" electricity in a bottle of water, by passing a rod into it from the prime conductor of a machine. The bottle was held in one hand, and after the machine

had been in operation a short time he attempted to remove the rod from the water with the other hand, when he was surprised and alarmed by receiving a shock. The news of this shock spread with great rapidity, and various modifications of the bottle of water were soon devised. The water served as the inside coat or conductor, and the hand of the operator as the outside coat. Let the pupil construct any or all of the following devices and take shocks from them.

465. Various Devices for giving Shocks.—**Experiment 170.**—Fill a small round bottle about two-thirds full of water. Put a piece of wire or a nail through a cork, and insert the cork in the bottle. The lower end of the wire must reach into the water, and the upper end must terminate in a ball or ring. Holding the jar in one hand, present the ball to a prime conductor, electrophorus, excited rod, or even a gutta-percha comb drawn through the hair. After the ball has taken several sparks, touch it with a knuckle of the free hand.

If it is at hand, paste tin-foil as a coating over the outside of the jar. A much larger condensing surface is thus obtained. Or, instead of the hand or tin-foil, set the jar in a vessel partly full of water, and dip a finger into the water while charging and discharging.

Experiment 171.—Paste a sheet of tin-foil on each side of a pane of glass. The foil should be smaller than the glass. Support the pane thus coated horizontally by one hand placed under the middle of it. Lay a coin on it. Bring the top coat, with the coin on it, near a prime conductor. After several sparks have passed, try to pick up the coin with one hand while the other is still in contact with the lower coat.

Experiment 172.—Let one pupil hold a pane of glass on the palm of one hand. Let a second pupil, who is standing on a stool with glass or rubber feet (see Exp. 175), rest his open hand flat on the glass, over the hand of the other, and bring a knuckle of the free hand near the prime conductor. After a few seconds, let them bring their free hands near together.

A class of inventive boys or girls will vary these experiments indefinitely. The shocks given by either of these devices, or by a regular Leyden jar, may be felt by several at once. To accomplish this, let all form a circle by clasping hands. When the circle is complete, break it in *one* place, and let the two persons thus separated touch, one the outside and the other the ball of the charged Leyden jar, or the corresponding parts of any other device.

A Leyden jar of a capacity of one quart will furnish a shock sufficiently severe for one person, though two or three times the amount of surface which it contains might be discharged through the human body without producing permanent injury. A large number of persons may take the discharge of a larger jar without injury.

466. Nature of the Discharge.—**Experiment 173.**—Set a wheel to rotating so rapidly that the spokes cannot be distinguished. Darken

the room and discharge a Leyden jar near the wheel. Not only will the separate spokes be seen, but the wheel will appear stationary. A rapidly-moving carriage-wheel, or even a cannon-ball, illuminated at night by lightning appears stationary. This shows that the electric spark is practically instantaneous.

Although the "disruptive discharge" of a Leyden jar, or of any condenser, appears thus instantaneous, refined experiments prove that it is really a *series* of discharges from positive to negative. Each discharge induces (see Art. 537) a weaker charge in the jar, which in turn is immediately discharged, inducing a still weaker charge, and so on till the jar is practically discharged, the whole constituting an "oscillatory discharge."

467. **Heat and Light from Electricity.**—In previous chapters we have learned that resistance to motion causes the molecular vibrations which produce heat and light. The same effect is produced by resistance to the free passage of electricity. Passing over a good conductor, electricity produces no visible effects. The particles of bad conductors are so *shaken up* by their unsuccessful attempts to stop the flow of the electric charge through them that they frequently develop, first, heat, then light. The ordinary electric spark is caused by the heating of the molecules of air and "dust" in the path of the discharge. When the electric spark is produced in any other gas, the color of the spark is characteristic of that gas in a state of incandescence.

It is a well-known fact that barns and other buildings are burned by lightning. Lightning is ordinarily due to a discharge between two clouds differently electrified, but in cases in which objects on the earth are "struck" it is a discharge between a cloud and the earth. Should it strike a poor conductor of comparatively small size in its line of connection with the earth, it develops heat, sometimes enough to fire the object.

The following experiments exhibit the heating power of the electric spark on a smaller scale.

Experiment 174.—Present a very shallow metal cup containing a spoonful of ether or carbon bisulphide to the prime conductor of a machine. The spark will ignite the liquid.

Experiment 175.—Support a dry board about one by two feet on three or *four stout* tumblers, bottles, pieces of wax, or on feet shod

with india-rubber. This is an *insulating stool*. Stand on this stool, and take in one hand a chain or wire leading from the prime conductor. Take in the other a cold, dry icicle. Presented quickly to a vessel of carbon bisulphide, or to an ordinary gas-burner, the bisulphide or the gas may be ignited. This is pretty sure to succeed best if the gas-burner is used, and turned upside down, the icicle being presented from below (Fig. 252). Any water that may chance to form will then run back on the icicle instead of collecting on the end in a drop, which tends to dissipate the charge and prevent a spark.

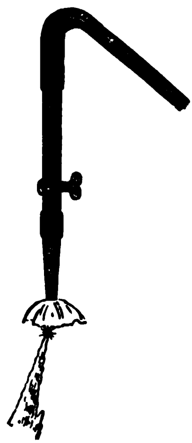

FIG. 252.—LIGHTING GAS WITH ELECTRIC SPARK FROM AN ICICLE.

Mixtures of oxygen and hydrogen, gunpowder, gun-cotton, and other explosives may be ignited by the electric spark. To fire gunpowder, the discharge must pass through a poor conductor, *e.g.*, a wet string, before reaching the metal ball suspended over the powder. Otherwise, by the suddenness of the discharge, the powder is blown away and not ignited.

468. **The Insulating Stool.**—The insulating stool affords a means of endless instruction and entertainment. A person standing on such a stool may be charged by connection with the prime conductor of a machine, or, standing near a conductor, he may be electrified by induction, or by presenting a knife-point or a row of pins to a prime conductor, or a revolving plate or cylinder, or excited rod, he may make a prime conductor of himself. In either case a few energetic schoolmates will think of a dozen expedients for testing his electric condition.

469. **Mechanical Effects of Electric Discharge.**—The electric shock is sufficient evidence that the passage of electricity through a poor conductor produces a shaking of the body, rather different from the molecular vibrations which produce heat. A loose block of wood is shaken by having a Leyden jar discharged through it. A piece of paper placed between the knob of a Leyden jar and the knob of the discharger is pierced by the discharge of the jar. A large jar, or several jars, will pierce thick cardboard, leather, and even glass.

470. **Thunder-Storms.**—Every one now knows that lightning and thunder are due to electricity. The discovery was made by Dr. Franklin but little more than one hundred years ago. How the electricity is produced in the air we are not prepared to say with certainty, but the friction of masses of air over one another, and between the air and particles of moisture and snow, and the evaporation and condensation constantly going on, are capable of developing a large quantity of free electricity. But, however developed, the free electricity is there at all times, though we are sensible of its presence mainly at the time of thunder-showers. The phenomena attending these storms may be explained by the principles which we have just learned. When a large number of molecules of atmospheric moisture condense and coalesce to form a cloud, the body of the cloud becomes a conductor, and all the electricity which may previously have been in the space now occupied by the cloud comes to the surface and there acquires considerable density. Different conditions give one cloud a charge of positive and another a charge of negative. It is plain that a discharge would take place between these clouds when they come sufficiently near to each other. Or a cloud heavily charged with either kind of electricity, on coming near a neutral cloud, would electrify it by induction, and a discharge might take place between the sides next to each other, which would be oppositely electrified. (Art. 441.) These are discharges between clouds. When a cloud heavily charged with electricity comes near the earth, it attracts the opposite kind of electricity by induction, and, as the earth has a large store to draw upon, or a large surface to distribute the repelled electricity over, the charge becomes very intense. In fact, we have a vast Leyden jar, the air acting as insulator. When the layer of air can no longer stand the strain, it is rent, the electricity of the cloud combines with that of the earth, and we *say the lightning* came to the earth. High objects are

most likely to be thus "struck," partly because the electric density on such would be greatest, and partly because the insulating air between the two charges is thinnest over such places. The sudden motion of the air along the line of the lightning discharge, caused by its displacement, and also by its expansion and contraction on account of the intense heat, is the probable cause of *thunder*.

471. **Lightning-Rods.**—We are now ready to understand the effect of the *lightning-rod*. If the charge excited in the earth by the electrified cloud finds a pointed conductor extending towards the cloud, it tends to flow from the point to the cloud, and thus the electricity of the cloud becomes neutralized by the quiet discharge from the point, and the flash of lightning and the "striking" are avoided. The most efficient lightning-rods are those furnished with several points. Even then there should be several on a large building to render it comparatively safe against the intense charges which clouds sometimes carry.

Lightning-rods should be of ample size and good metal. Wrought-iron rods should be nearly an inch in diameter. Copper rods may be somewhat smaller. They should run several feet into the ground, and be connected with buried water-pipes (if they are large), or else they should terminate in several branches and be packed in coke, which is a good conductor.

472. **Electricity in Rarefied Air.**—Though the air in its ordinary state is a non-conductor of electricity, highly-rarefied air carries a charge with but little resistance. The aurora borealis, which is sometimes seen in our latitude, and more frequently in the far north, is probably due to electric currents in the higher and rarer regions of the atmosphere.

A philosophical-instrument-maker will furnish an "aurora-tube," with which a beautiful experiment may be performed. The tube has a pointed metal rod sealed into the upper end, and the lower end fits the air-pump. On exhausting the air and connecting the rod at the top with the prime conductor of a machine, the tube is filled with *beautiful* rosy streams of light, visible in a dark room. The electri-

fied particles of air remaining in the tube, and which produce the light, are attracted like other electrified bodies, and the streams may be diverted towards the hand placed against the outside of the tube. In a succeeding section the subject of electric currents in rarefied gases will be more fully treated. (Art. 540.)

Exercises.—1. Two boys stand on different insulating stools, and one strokes the other a few times with a cat's skin: what will be the difference in their condition, and how may it be shown?

2. A girl on an insulating stool presents a row of pins to the prime conductor of an electrical machine in operation: what is her electrical condition?

3. If the induction-cylinder of Experiment 162 be touched to the prime conductor of a machine, what will be its condition after being removed?

4. Let the pupil draw a diagram representing three insulated conductors in a row, but not touching, that at one end connected by wire with the prime conductor and that at the other end with the negative conductor: indicate by the signs + and — the condition of each end of the middle cylinder.

5. If an excited rod be held over some very small pith balls lying on a table and then over some others lying on a pane of glass, what difference in their behavior should be noticed?

6. Two small spheres, each charged with a + unit of electricity, are placed ½ centimetre apart: with what force do they repel each other? *Ans.* 4 dynes.

7. Two equal spheres, one having a charge of 4 + units and the other a charge of 2 — units, are placed 1 centimetre apart: what is the force of attraction between them? If they touch and rebound, what is the force of repulsion when at a distance of 1 centimetre? *Ans.* 1 dyne.

8. Two balls at a distance of 4 centimetres attract each other with a force of 16 dynes. One has a charge of 32 + units. What is the charge of the other? *Ans.* 8 — units.

9. A stationary ball is charged with 490 units of + electricity. A suspended ball 1 centimetre distant, weighing 5 grams, is repelled from it with the force of 5 grams: what is its charge? *Ans.* 10 + units.

II.—ELECTRICAL CURRENTS.

473. **Introductory.**—The phenomena of the last section were treated under the heading "static electricity," because the appliances used developed electricity as a static,—*i.e.*, *standing* charge, and as such it was studied. The general subject is termed "electrostatics." The phenomena of electricity flowing as a *current* are embraced in the general subject of "electrodynamics," and electricity thus doing

work is called "current,"—*i.e.*, *running* electricity, because it manifests itself while running. In honor of two early experimenters with it, current electricity is sometimes called *galvanism*,[1] and sometimes *voltaic*[2] *electricity*, or the *voltaic current*. "Galvanic battery" and "voltaic battery" are general terms applied to all forms of battery producing current electricity.

474. **The Two Identical.**—There is no difference implied between the electricity developed in one way and that developed in any other way. Friction and induction readily yield static charges of great electro-motive force, while the battery, the dynamo, the thermopile, and magneto-induction readily yield currents.

475. **Principle of the Voltaic Battery.**—The origin of the electric current produced by a battery is chemical action between two substances, generally an acid fluid and a metal.

Experiment 176.—Put into any convenient small glass vessel a mixture of 1 part of sulphuric acid to 10 or 20 parts of water. Dip into this a strip of zinc and a strip of copper. A copper cent, fastened to a wire, answers very well for the copper strip. Set the vessel in a light place and examine the liquid near each metal strip. Minute bubbles may be seen rising from the sides of the zinc, but none from the copper. Touch the zinc and copper together above the surface of the liquid, the lower parts remaining immersed. Bubbles will begin to rise rapidly from the copper plate, and a few will probably continue to rise from the zinc. Separate the metals, and the bubbles stop rising from the copper plate.

These bubbles are hydrogen gas, liberated from the water (which is composed of oxygen and hydrogen) by the chemical union of the zinc with the other elements of the acid fluid. This chemical action is accompanied by the develop-

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[1] Aloisio Galvani, Italian, 1737–1798, Professor of Physiology at Bologna, discovered that a piece of copper and a piece of zinc in contact with the nerves and muscles of a dead frog, and with each other, give rise to a current of electricity.

[2] Alessandro Volta, Italian, 1745–1827, discovered that any two metals in contact, and in a situation to be chemically acted on, give currents of electricity. He was the inventor of Volta's pile and of the simple voltaic or galvanic battery.

ment of electricity, which, when the metals are in contact, or connected by a wire, takes the form of a "current" through the wire, from the copper to the zinc. This chemical action and electrical excitement are inseparable, one undoubtedly dependent on the other. *If the chemical action is stopped, the current ceases; and if the current is stopped, the chemical action ceases.*

476. **Pure Zinc needed.**—The continuous rise of bubbles from the zinc is due to slight traces of some other metals as impurity. The particles of such metals being in contact with the zinc, a number of small "local" currents are established. This action uses up the zinc without giving any compensation in the way of a current over the wire, where only we can make use of it. A pure metal by itself is not dissolved in the dilute acid. The surface of the zinc is rendered practically pure by coating it with mercury. The mercury dissolves the zinc, floats out the impurities, and so works towards the middle of the bar, leaving pure zinc on the surface. Zinc so treated is said to be *amalgamated.*

Experiment 177.—To amalgamate zinc, dip it into dilute sulphuric acid for an instant, and then rub it or slap it with a little muslin bag containing an ounce or two of mercury. Make it shine all over, and repeat Experiment 176, using the amalgamated zinc.

FIG. 253.—VOLTAIC CELL.

477. **The Simple Voltaic Cell.**—The apparatus employed in the last experiment is esentially a voltaic cell. Fig. 253 shows a form of nicely-made cell. The zinc and copper are indicated. Two metals (or elements) are needed in each cell, and they must be such that they are acted upon at different rates by the acid. This gives different potentials to the two plates, and insures a current between them. The more readily an element is acted on, the higher its potential, and the more difference in this

24*

respect between the elements, the greater the difference of potential, and the greater the electro-motive force (Art. 491) of the cell. In most battery cells the negative element is not dissolved at all by the battery fluid. In the figure, the current flows as indicated by the arrow.

478. **The poles, or terminals,** are the upper ends of the plates, or the wires connected with them. The wire, the plates, and the liquid between the plates constitute the *circuit.* Any machine, lamp, telegraph instrument, or anything of the kind connected with the wire so that the current flows through it, is *in the circuit.* If electrical connection is *complete* from any point in the circuit around to the same point, the circuit is *closed.* If *any break exists,* it is *open.*

479. **Polarization of Cell.**—Many combinations of metals, or elements and fluids, are used in the construction of different kinds of batteries. Theoretically, the cell just described should give good results, as zinc is very easily acted upon and copper with much difficulty by the acid employed, thus giving much difference of potential. In practice, however, the cell very soon becomes *polarized,—i.e.,* bubbles of hydrogen collect on the copper and retard the action, partly by its non-conducting property and partly because it is not distinctly negative in chemical behavior. It is important to get rid of this coating of hydrogen. This may be accomplished by constant agitation of the cell, or by blowing air into it. This is troublesome, and affords only temporary relief.

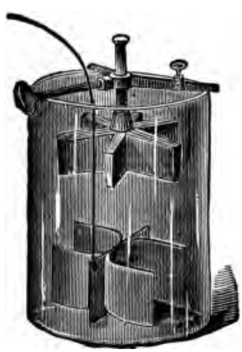

FIG. 254.—GRAVITY CELL.

480. **The Gravity Cell.**—Fig. 254 shows the gravity cell, in *common* use on telegraph lines as the "local battery" at way-stations.

It avoids polarization by using a solution of blue vitriol or "blue stone" (copper sulphate), instead of sulphuric acid. The copper plate is placed in the bottom of the cell, and has an insulated wire extending out. The zinc is suspended in the top. The hydrogen, instead of adhering to the copper, decomposes the copper sulphate, forming sulphuric acid and copper. The copper adheres to the copper plate, while the sulphuric acid finds its way to the zinc, which it dissolves, and thus furnishes the current. The zinc sulphate solution thus formed floats on top of the jar, while the heavier copper solution remains at the bottom. The fact that the two fluids are kept measurably separate by gravity gives the cell its name.

481. **Other Single-Fluid Cells.**—Gas carbon may be used instead of copper for the negative element of a cell. Gas carbon and zinc, in an acid solution of bichromate of potassium, form a very convenient and effective battery for experimental purposes. This is the "one-fluid bichromate battery." A dozen other single-fluid cells might be mentioned. Zinc is almost always used as the positive element, —*i.e.*, the element dissolved by the acid.

482. **Two-Fluid Cells.**—The polarization of the cell is most effectually obviated by the use of two fluids,—one especially to dissolve the zinc, and the other to present something for the hydrogen to unite with. One of the oldest and most constant of this form is

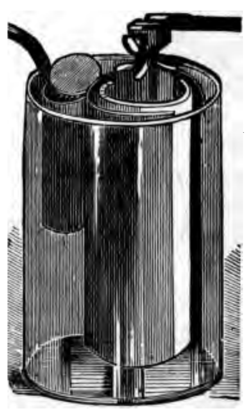

FIG. 255.—DANIELL'S CELL.

483. **Daniell's Cell,** shown in Fig. 255. The jar contains an open cylinder of copper, with a copper pocket riveted to its top half. Inside the copper cylinder is a porous jar of unglazed earthenware, and in this a rod of zinc. The zinc is immersed in dilute sulphuric acid contained in the earthen jar. The glass jar contains a solution of copper sulphate, and the pocket contains crystals of the same, to keep the solution saturated. The porous jar will not allow the fluids to mix to any extent, but it soon becomes soaked, and offers little obstruction to the molec-

ular action and the consequent electric current, which are kept up as though the partition did not exist. The action is otherwise like that of the gravity cell.

484. Grove and Bunsen Cells.—The Grove battery is one of the most powerful in ordinary use. The porous cell contains nitric acid in which platinum is immersed. This is set in a jar containing a zinc plate in dilute sulphuric acid. The hydrogen unites with oxygen of the nitric acid, forming water. The Grove battery is expensive, runs down in intensity very rapidly, and emits very corrosive nitrous fumes, so that it is used where strength of current is needed at the expense of other advantages. When gas carbon is used instead of platinum, we have Bunsen's battery. (See Figs. 258 and 259.)

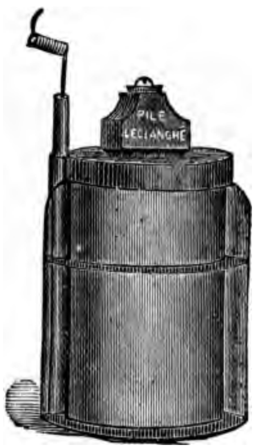

FIG. 256.—LECLANCHÉ CELL.

485. The Leclanché Cell (Fig. 256) is much used for electric bells, telephones, and other open-circuit work where but little energy is required. It is of various forms. A small zinc rod stands in one corner of the jar in a solution of sal ammoniac. The carbon plate is packed in manganese dioxide, which gives up oxygen to the hydrogen bubbles, and depolarizes the cell. The manganese dioxide gives up oxygen slowly, so that if the battery is used for even a few minutes continuously it becomes polarized, and its power falls considerably. After standing awhile, however, the hydrogen disappears, and the battery is ready to work again. If the jar is kept covered to prevent evaporation of the water, a battery of this kind will operate an ordinary door-bell for a year without attention.

Works specially devoted to electricity describe many additional kinds of cells, both single-fluid and two-fluid, some using liquid, or even gaseous elements, in place of the zinc and copper, etc., here described.

486. Distinction of Positive and Negative.—We speak of the wire attached to the copper or carbon of a cell as the *positive pole*, while we speak of the copper or carbon plate *itself* as the *negative element*. The reason for this will be

made clear if we remember two things: First, that positive and negative are determined by the *direction of flow* of the current, which is always from *positive* to *negative*—from the *higher* to the *lower* potential. Second, that the current *originates* on the surface of the zinc, flows *through the liquid* from zinc to copper, making the *zinc* positive in the battery, and through the *wire* from the copper to the zinc, making the *copper* positive in the air. (See Fig. 253.)

487. **Batteries of Several Cells.**—The term "battery" has been used unavoidably several times in the last few pages. The different arrangements which have been described as

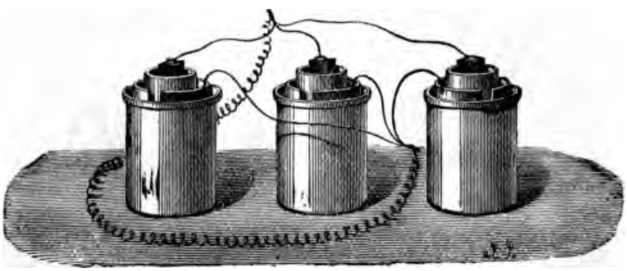

FIG. 257.—BATTERY CONNECTED IN PARALLEL CIRCUIT.

producing the voltaic current are properly *cells*, or *couples.* A cell of given construction gives a current of definite *electro-motive force* (Art. 491), the *quantity of current* (Art. 493) depending upon its size. In order to obtain more electro-motive force or more current than one cell will give, several cells are connected by wires, and *together* form a voltaic *battery.* Fig. 258 shows a Bunsen's battery of two cells, and Fig. 259 one of four cells.

488. **Connection of Battery Cells.**—In Fig. 259 it will be seen that the carbon of the first cell is connected with the zinc of the second, the carbon of the second with the zinc of the third, and so on. If, with the carbons and zincs thus connected through the battery, a wire be carried from the carbon of the last cell to the zinc of the first, the circuit

is completed, and the current flows. Cells thus joined are connected *in series*.

In Fig. 257 the zincs are connected by separate branches to the main wire or *lead*, and the carbons are similarly connected to another lead. When the two leads are connected the circuit is completed, and the current flows. This is called connecting cells in *parallel circuit*, or *multiple-arc*.

Connection in series gives the greatest electro-motive force; connection in parallel circuit gives the greatest

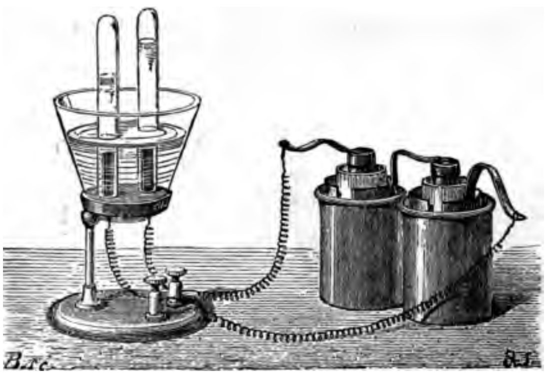

FIG. 258.—ELECTROLYSIS OF WATER.

strength of current under some conditions. (See Art. 507.) With large batteries it is sometimes advantageous to connect three or four together in series, all through, and then connect these *groups* in parallel circuit.

489. **Electrolysis.**—If the terminals of a battery be dipped into water, or acid, or a solution of a salt, so that it is made *part of the circuit*, the liquid, whatever it be, is decomposed on the passage of the current through it. The terminals of the battery when thus immersed in a compound liquid are called *electrodes*. That electrode through which the current flows *into* the liquid is the *anode* (Greek, **ascent**) and that by which the current *leaves* the

kathode (Greek, descent). The liquid to be decomposed is the *electrolyte.*

Fig 258 shows an apparatus for the electrolysis of water. The vessel and tubes are filled with water containing a few drops of sulphuric acid to increase its conducting power. When the current passes, bubbles of gas rise and fill the tubes, oxygen rising at the anode and hydrogen at the kathode. The action is increased if the tubes are held an inch above the bottom of the glass, or quite above the electrodes. As water is composed of two volumes of hydrogen to one of oxygen, one tube will collect gas twice as fast as the other.

490. **Electro-plating.**—When the electrolyte is a solution of a metallic salt, the metal separates at the kathode in a

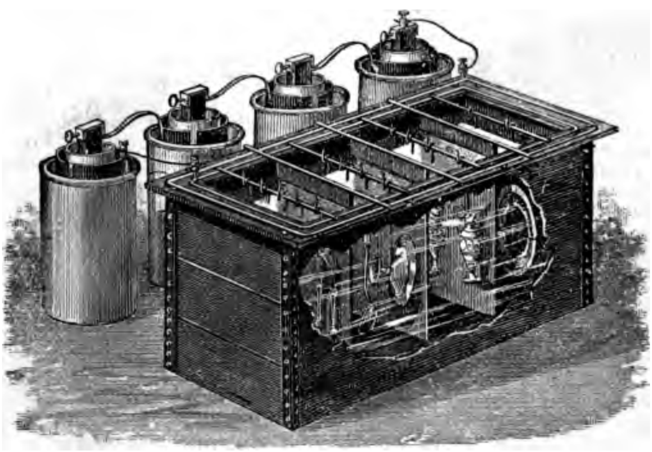

FIG. 259.—ELECTRO-PLATING, WITH BATTERY OF FOUR BUNSEN CELLS.

pure state. Several of the metals were thus discovered by Sir Humphry Davy in the early part of the nineteenth century. If we wish something plated with silver, gold, or nickel, it is made the kathode, and a plate, generally of the metal itself, is made the anode, in a solution of some salt of the metal. On closing the circuit through the electrolyte, the metal is deposited.

Fig. 259 shows a silver-plating tank in operation. The vessels and other articles which are being plated are all suspended from the rods which are connected with the zinc electrode of the battery. The large square plates suspended from the positive electrode are pure silver, which is dissolved as the process goes on and keeps the solution of a uniform strength.

Any boy or girl, with very little outlay, may find instructive entertainment in electro-plating. The apparatus here figured may be of very much smaller dimensions. The battery may be home-made, a tumbler will hold the plating-solution, and a brass watch-chain or hook, or a copper cent, may be plated. In fact, plating may be done *in the battery*, and that may be easily constructed.

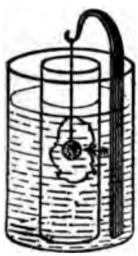

FIG. 260.—SILVER-PLATING A COIN.

Experiment 178.—Put a small silver coin into a dish and pour over it a few teaspoonfuls of nitric acid. (It should be out of doors or in a fireplace, as the fumes are hurtful.) If the acid is strong, put in as much, or twice as much, water. Heat the dish moderately. The coin will dissolve rapidly. When the coin has disappeared, pour the solution into a glass vessel. Add some weak "muriatic" acid, or a strong solution of salt in water, as long as it continues to form white "curds" in the liquid. These white curds are chloride of silver. They will settle to the bottom of the vessel. Pour off the blue liquid, or most of it. Fill up the vessel with water, and pour off several times. This is to remove the copper with which the silver of the coin was alloyed. It is blue in the solution, and when the blue color disappears the chloride of silver is washed enough. Partly fill the glass with water and add cyanide of potassium, stirring till the white curds are all dissolved. (Caution: Cyanide of potassium is *intensely poisonous*. Don't put your hands or any of your work near your *mouth*.) Add water enough to make the solution up to a half-pint for each *dime* dissolved. Fill a porous battery cup with this, or, if that is not at hand, a flower-pot with the hole stopped with plaster or putty, or, for a small quantity, the "bowl" of a tobacco-pipe with a plug in the broken-off stem. Set this in any convenient glass vessel, and fill that with dilute sulphuric acid to the level of the silver solution. Put a piece of zinc in the outer vessel, and suspend from it by a wire a small *clean* article to be plated. Take it out and rub it with a cloth after a minute. Repeat several times, each time leaving it in longer. In ten minutes there will be a very good plating, and in an hour or more, depending on the strength of the current, a really thick plating.

Some of the terms most frequently used in the practical applications of electricity are here defined, and some of the units used in *electrical* measurements are named with such definitions only as will

give an idea of their magnitude. Further definitions of the units will be given as we learn the meaning of the terms which it is necessary to use in those definitions. (See Arts. 502 and 557.)

491. **Electro-Motive Force.**—Electro-motive force (written E. M. F.) is that which causes electricity to flow. As the current flows from the higher to the lower potential, the electro-motive force of a current indicates the difference of potential between two points. The E. M. F. of a battery is the difference of potential between the positive element subjected to the chemical action of the fluid it is immersed in and the negative element subjected to similar action. For a given cell it is *always the same*, as the laws of chemical affinity are invariable.

492. **The Unit of E. M. F.**—The practical unit of electro-motive force is the *volt.* (See Art. 503.) It is rather less than the E. M. F. of one ordinary cell; thus, the Daniell cell is about 1.1 volts, the Leclanché about 1.5, the Bunsen about 1.8, etc. When a battery is connected in *series*, the E. M. F. of the battery is the *E. M. F. of one cell multiplied by the number of cells.*

493. **Quantity of Current.**—The quantity of current, or strength of current, generated by a battery of given construction, increases with the *size* of the plates employed, or with the number of cells connected in parallel circuit. This will be made more clear after a statement of Ohm's Law. (Art. 506.)

494. **Unit of Current.**—The practical unit of current is the *ampere.* (See Art. 504.) It may be defined at present by its electrolytic action. A current of one ampere, passed through a solution of blue vitriol, will deposit on the kathode 1.174 grams of copper per hour. The amount of any metal deposited from solution is *directly proportional to the strength of the current*, measured in amperes.

The current flowing through 100 miles of iron telegraph-wire from a battery of 15 Grove cells would be possibly $\frac{1}{50}$ of an ampere. This would be read 20 milli-amperes. An incandescent light [illegible]

requires ¼ ampere at 80 volts, and 100 such connected parallel require 100 times as much.

495. **Unit of Electric Work.**—In mechanics we express work done in horse-power. It would require 33,000 lbs. falling one foot a minute to equal one horse-power. So in electrodynamics, the quantity of current in amperes may stand for *weight*, the E.M.F. in volts may stand for *height*, and the *product* of these equals the *working power* of the current. The *watt* is the working-power of a current of one ampere flowing with an E.M.F. of one volt. There are 746 watts in one horse-power. The *kilowatt* is 1000 watts, or about 1⅓ horse-power.

This is the *theoretical ratio* of watt to horse-power, and means the work which one watt is capable of doing in a perfect electric motor. In practice it requires nearly twice as much horse-power in the engine driving a dynamo for motor-work as calculations based on this ratio would give.

496. **Resistance.**—Resistance is simply that which opposes the flow of the current. In all conductors there is some resistance. There is resistance in the fluid of a battery, in connecting wires and leads, and in the instruments connected in circuit. The resistance of battery fluid, etc., is the *internal* resistance, and the resistance of leads, machinery, lamps, etc., is the *external* resistance of a circuit. Resistance in the battery and in the leads is waste energy; resistance in lamps, coils, etc., is *not* waste energy, for it converts the electricity into light, magnetic force, etc., for which it was generated. In fact, the work done by a given current in any part of its circuit is proportional to the resistance of that part of the circuit.

In a wire of given material the *resistance is directly proportional to the length, and inversely proportional to its area in cross-section.* In round wires of the same material the resistance varies *inversely as the square of the diameter.*

497. When the resistance is considerable, an appreciable amount of heat results. Thin wires of platinum and thin strips of carbon are *readily* rendered white-hot by the passage of the current. If a copper

or iron conducting-wire from a battery be cut in one or more places, and pieces of thin platinum wire be stretched across the breaks thus formed, they become white-hot on the passage of a moderately-strong current, and will ignite illuminating gas, gunpowder, or any similar substance in which they may be placed. Such arrangements are used in lighting the gas in high situations and in blasting in mines. Platinum offers much more resistance than copper, and the thin wire more than a thicker one would. Thick telegraph-wires are better for their purpose than lighter ones.

498. **The Incandescent Lamp.**—The incandescent electric lamp consists of a small ribbon of paper-charcoal in the form of a horse-shoe, placed between metal tips in a glass globe from which the air has been exhausted. Fig. 261 shows the general appearance of the lamp. A current being passed through from one of the wire ends to the other, the carbon is intensely heated on account of its resistance. As no air is present, it cannot burn away, and so will give a continuous light for many weeks or months. Some incandescent electric lamps use platinum instead of carbon.

FIG. 261.—EDISON'S ELECTRIC LAMP.

499. **Division of Current.**—If two conductors extend between the plates of a battery, or are so introduced into a circuit that the current may take either, a part of it takes each route, and the amounts are in the inverse ratio of the resistances of the conductors. If, for instance, two copper wires of equal length and equal thickness extend between two points in a circuit, half of the current will follow each. If two points in a circuit be connected by two copper wires, one of which is $\frac{1}{10}$ of an inch in diameter and the other $\frac{1}{20}$ of an inch, and both of the same length, the larger wire will carry $\frac{4}{5}$ of the circuit, and the smaller $\frac{1}{5}$. In this way currents are frequently *divided* for purposes of electric lighting, duplex telegraphing, etc. So a current may be divided into *any number* of parts.

500. ***Dividing* a Current for Measurement.**—The division of

the current is practically applied to determining the amount of electricity used by consumers in a town where a company furnishes the supply. The wire supplying the house is divided after leaving the lead, one division being very fine compared with the other. A branch wire from the main lead, such as this, is a *shunt circuit*. The shunt circuit b includes a solution of blue vitriol (as shown in Fig. 262). The resistance of the wire bb, and the solution c, is many times that of the short circuit a, say 999 times as great. The inspector occasionally removes and weighs the copper plate which forms the kathode in c. The increase in weight indicates the amount of current which has passed through c, and this multiplied by 1000 (999 + 1) gives the whole current, generally expressed in "ampere-hours."

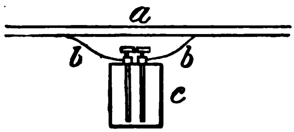

FIG. 262.—VOLTAMETER.

501. **Unit of Resistance.**—The practical unit of resistance is the ohm. (See Art. 505.) It is the calculated resistance of a column of mercury one millimetre in cross-section and 1.06 metres long.

A copper wire, No. 10, which is almost exactly $\frac{1}{10}$ of an inch in diameter, has a resistance of one ohm in 962 feet. An iron wire of the same size gives one ohm for 160 feet. Ordinary telegraph-wire, No. 6, has a resistance of about 13 ohms per mile. Silver has the least known resistance, copper but little more, iron and platinum about six times as much as copper.

502. **Definitions of Units.**—Three of the units mentioned above depend on one another so completely that the definitions of all, and of some others, were left till we could properly use any of the terms in defining any of the others. The units here given are practical units, derived from a system of "absolute" units which are mostly much too small for convenient measurement or use. (See Art. 557.)

503. **The Volt.**—The volt is the electro-motive force which will cause a current of *one ampere to flow through a resistance of one ohm.* (See Art. 557 for derivation of the volt.)

504. **The Ampere.**—The ampere is the current (or strength of current) caused by an electro-motive force of *one volt against a resistance of one ohm.* The *coulomb* is the *amount*

of the above current passing a given point in *one second.* It represents a *definite quantity* of the molecular or ethereal *action, or energy* known as *electricity.*

505. **The Ohm.**—The ohm is the resistance *against which an electro-motive force of one volt can maintain a current of one ampere.*

506. **Ohm's Law.**—The relation of the three practical units, the volt, the ampere, and the ohm, is evident from the definitions. As a result of the three definitions, we learn that the E. M. F. tends to urge the current forward, the resistance tends to stop it, and the resulting current represents how many times greater the E. M. F. is than the resistance. Dr. Ohm discovered this relation, and gave us the important law which bears his name. It may be stated thus: *The current from a given source varies directly as the electro-motive force, and inversely as the resistance.* If we use the three units above defined, we have the algebraic expression of Ohm's law,

$$C = \frac{E.}{R};$$

that is, the E. M. F. in volts, divided by the resistance in ohms, gives the current in amperes. Practical problems in the application of Ohm's law are given at the end of the chapter.

507. **To Connect Battery Cells.**—We are now ready to understand why batteries connected in parallel circuit are for some purposes more efficient than those connected in series. For purpose of illustration we will refer to the battery shown in Fig. 259. The E. M. F. is the same in each of the four cells, and so is the resistance. If we put the former at 1.8 volts, and the latter at .5 ohm, we have total E. M. F. of battery $1.8 \times 4 = 7.2$ volts, and total resistance $.5 \times 4 = 2$ ohms. Therefore current, $7.2 \div 2 = 3.6$ amperes.

If the cells be connected in parallel circuit, as shown in Fig. 257 (supposing there were *four* of them), the resistance would be only one-fourth the resistance of one cell in the other case, for the current would have to flow through a conductor (the liquid of the cell) just as *far* as in each of the series cells; but as it starts from four zincs at once, the

conductor would have four times the cross-section of one cell, therefore the resistance would be $\frac{1}{4}$ what it was previously. The E. M. F. is not increased by parallel connection. Therefore the current would be $1.8 \div .125 = 14.4$ amperes. This shows *more* current from the parallel connection than from the series connection, but we have not counted the resistance of the external circuit.

508. **To Determine the Best Method** of connecting battery cells, divide the E.M.F. by the *total* resistance of the circuit, internal and external, and adopt that which gives the largest result in amperes. It will be found that in short circuit of small resistance the parallel connection is best; in long circuits of high resistance the series connection is best; while in some intermediate circuits the best result comes from a combination of the two.

For purposes of electrolysis, the E.M.F. of the battery must be greater than the E.M.F. which represents the chemical affinity of the elements to be separated. For instance, the union of oxygen with hydrogen to form water represents an E.M.F. of nearly 1.5 volts. *One* Daniell's cell could, therefore, never decompose water, though *two* cells accomplish it readily if connected in series.

509. **Secondary Batteries.**—We have seen that the current from a battery has the power of separating many compounds into their constituent parts. The reuniting of substances thus separated will, under proper conditions, give rise to a voltaic current opposite in direction to the current which caused the decomposition. This fact is made use of in the construction of secondary, or so-called "storage," batteries.

Among the most successful secondary batteries are Faure's (fŏr) and some of the numerous modifications of it. The principle may be understood from a description of the original form, devised by Faure. It consists of two large plates of very thin sheet-lead, each coated with a layer of minium (red oxide of lead), and rolled together into a spiral like a roll of carpet. The sheets are kept separated by rolling in with them soft paper saturated with weak acid. One of *these* sheets is connected with each of the wires from a battery. Oxygen from the weak acid is liberated on the surface of the lead plate

which forms the positive electrode, and hydrogen on the surface of that which forms the negative electrode. The oxygen unites with the coating of red lead on the positive sheet, converting it into a higher oxide of lead. The hydrogen unites with the oxygen of the red lead coating on the negative sheet, and forms water, reducing the oxide of lead to pure lead in a very fine state of subdivision. When all the red lead on one sheet has been converted into the higher oxide, and all that on the other has been reduced to the condition of metallic lead, the secondary battery is said to be "charged." If, now, the wires are disconnected from the charging battery and brought into contact with each other, a current will be found to pass through them, and, as said before, it flows backward with reference to the direction of the primary current, or from the oxidized to the deoxidized plate.

510. **Energy of Secondary Battery.**—The total amount of energy given out in the discharging of a secondary battery is, of course, equal to that consumed in charging it, and in practice this may nearly all be made available. The total quantity of an electric current, or of the energy of a given current, is equal to the amount for any unit of time multiplied by the time during which the current flows. A secondary battery may be charged by a small battery working for a considerable length of time, and may be discharged in a powerful current flowing a proportionately short time. This feature renders it admirably adapted to electric lighting, or to the driving of electric motors, where such use is needed for but a small part of each day. The secondary battery is also very much lighter than a primary battery required to give a current of equal intensity. It is thus adapted to use where the size and weight of a large battery are an objection. It has already been applied to driving road-carriages and to lighting steamships and railway-cars.

III.—ELECTRO-MAGNETISM AND MAGNETO-ELECTRICITY.

511. **Oersted's Discovery.**—About the year 1820, Hans Christian Oersted (ur′sted), Professor of Physics at the University of Copenhagen, discovered that a wire through *which a voltaic* current is flowing has the power of de-

flecting a magnetic needle out of the meridian. This discovery at once established the connection between electricity and magnetism, and laid the foundation for the many useful applications of electro-magnetism. Oersted also discovered that the conducting wire of a battery is magnetic while the current is passing.

512. **Magnetic Field of Electric Current.**—If a wire carrying a current from several cells be passed through a hole in a rigid piece of cardboard, iron-filings sifted on the card will arrange themselves circularly around the wire, somewhat as shown in Fig. 263, the filings being rendered magnetic. This demonstrates the existence of lines of magnetic force and a magnetic field around the conductor, and calls to mind the field surrounding a magnet. The deflection of the needle by the conducting wire shows that there is a *rotation* of the magnetic force *around the conductor.* Just *what* rotates we cannot stop to discuss, but the rotation always exists, and always in a definite direction.

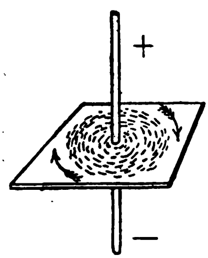

FIG. 263.—LINES OF FORCE AROUND ELECTRIC CURRENT.

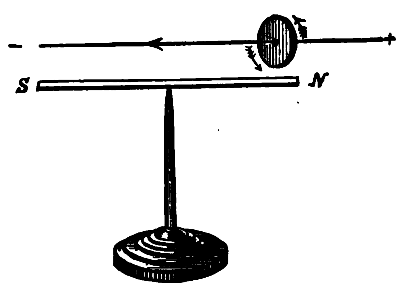

FIG. 264.—SHOWING DIRECTION OF NEEDLE'S DEFLECTION.

513. **Direction of Deflection.**—Reference to Fig. 264 will make plain the direction in which the needle is deflected. The direction in which the *current flows* is indicated by the signs + and —, and the direction in which the magnetic force rotates is indicated by the arrows on the wheel. If *we look* along the wire *with the current,—i.e.,* from + to —,

—the rotatation, or "magnetic whirl," is in the direction in which the hands of a watch move, and its deflecting force is exerted on the *north pole* of the magnet. If the current pass from north to south *over* the needle, the north pole is sent *eastward;* if *below* the needle, it is sent *westward;* if on a level with the needle at the *right*-hand side, it is *raised;* if on the *left*, it is *depressed.*

514. **The Amount of Deflection** of a given needle depends on the total effective strength of the current. A given current may multiply its effect on the needle by passing several times. If one current pass above a needle from north to south, and another pass beneath it from south to north, the two currents will tend to deflect the needle in the same direction, and the effect will be a double deflecting force. The same result is obtained when the wire is bent so that the *same* current may pass in one direction above the needle, and in the other direction under it. The result is intensified by so coiling the wire as to make the current pass many times around the needle. This principle is made use of in the construction of the *galvanometer*, or instrument for detecting and measuring the galvanic current.

FIG. 265. GALVANOMETER.

515. **Galvanometer.**—Fig. 265 represents a common form of galvanometer. It has a double, or *astatic* needle,—*i.e.*, two magnetic needles so arranged that they neutralize each other's tendency to stand north and south,—suspended by a thread of "unspun" silk. The graduated circle which lies on the coil of wire, and just under the uppermost needle, indicates the amount of deflection.

516. **Ampere- and Volt-Meters.**—In any galvanometer, the amount of deflection is proportional to the strength of the current. As currents vary in strength very much, the galvanometer must be

constructed with special reference to the use to be made of it. For induced currents (Art. 541), currents that have travelled many miles on telegraph-wires, etc., a galvanometer constructed essentially as that shown in Fig. 265 would be used. For measuring strong dynamo-currents in amperes, for determining the E. M. F. of currents, etc.,

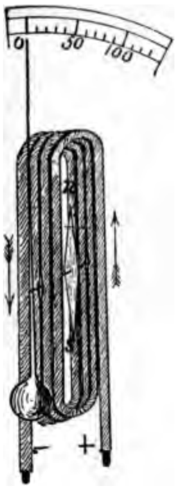

FIG. 266.—AMPERE-METER.

FIG. 267.—VOLT-METER.

special forms are devised, called *ampere-meters* (or "ammeters"), *volt-meters*, *watt-meters*, etc.

Fig. 266 will give a general idea of one form of ampere-meter. The galvanometer needle stands vertically, and is weighted at the lower end, so that the index is at 0 when no current is passing through the coil. The stronger the current the further the needle is deflected towards the right, and the graduation is in amperes.

The volt-meter generally has a coil consisting of a great many turns of very fine wire. This is connected in *shunt circuit* (Art. 500) with the lead which carries the current, whose E. M. F. is to be determined. The wire being fine has a high resistance, and the amount of current passing through it is dependent upon the E. M. F. The details of construction are somewhat complex, but the deflection of the needle is read in volts, and the needle is returned to the 0 point by a permanent *steel* magnet or by a spring.

517. Wheatstone's Bridge.—The Wheatstone's bridge, or balance, is extensively used in the measurement of *resistances*, and inci-

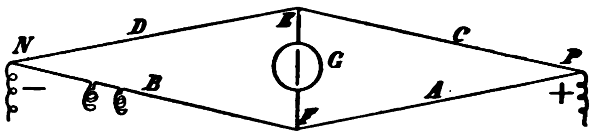

Fig. 268.—Wheatstone's Bridge.

dentally in the measurement of temperature and other circumstances which affect the resistance of wires. The *principle*, not the form, is shown in Fig. 268. A conductor is divided at P and reunited at N, giving the bridge four *arms*, A, B, C, D. E and F are joined by a wire containing a galvanometer, G. If the arms have *equal* resistances, the current flows equally from P to N by way of AB and CD. Suppose A and C are equal in resistance, but that D's resistance is greater than B's. Then part of the current will pass to B over EF, and deflect the galvanometer. Wires of *known* resistance are then placed in circuit in the arm B, until the needle G comes back to 0. In this way the resistance of D is obtained.

Fig. 269.—Resistance-Box.

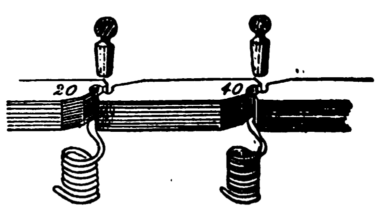

Fig. 270.—Connection of Resistance Coils.

518. Resistance Coils and Boxes.—A resistance coil is a coil of insulated wire of known length and diameter, having, *consequently*, a known resistance. A resistance-box is

a box containing many of these coils for practical use. A common form is shown in Fig. 269. The figures indicate the resistance in ohms of each coil. Any or all of these coils may be thrown into circuit at once by withdrawing the plugs, as shown in Fig. 270. The plug (brass or copper) when in place carries the current.

519. **To Measure Resistances.**—The resistance of any conductor, whether battery fluid or plating bath, telegraph line or ocean cable, electric-lamp or magnet-coil of a dynamo, is accurately determined by means of the Wheatstone's bridge and resistance-box.

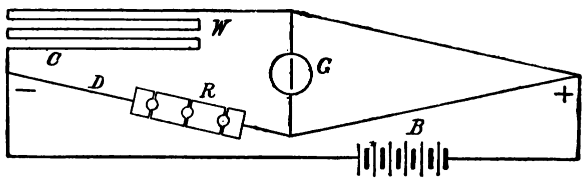

FIG. 271.—MEASURING RESISTANCE.

In Fig. 271 a current from the battery B passes through the bridge. (Batteries are commonly represented in plans by alternate light and heavy parallel lines, the light lines representing zinc, and the dark lines carbon.) The arm D contains the resistance-box R. The arm C contains the wire W, to be measured. Plugs are pulled from the box till the needle *G* stands at 0, and the sum of the numbers on the coils thus thrown into circuit is the resistance of *W*.

The resistance of a wire may be determined by the resistance-box and galvanometer, without the bridge. The current from a battery is sent through the line and a galvanometer, and the deflection read on the scale of degrees. The line is then thrown out and a resistance-box put in the circuit in its place. Plugs are drawn until the galvanometer reads the same that it did previously. The reading of the box is the resistance of the line.

520. **Breaks in Ocean Cables.**—When an ocean cable breaks, the broken ends make a good ground connection, and, the resistance of *the earth* being practically nothing, the position of the break is readily

determined. The resistance of the whole cable is carefully measured before it is laid down, and frequently thereafter. If at any time it stops working, the resistance is tried from both ends, and the broken cable grappled up and repaired. Suppose, for instance, the cable extending from Valentia to St. John's should be found broken, the resistance of the Valentia end being one-fourth that of the whole cable, and the resistance of the St. John's end three-fourths, the break is one-fourth the distance from Valentia to St. John's. This cannot be applied to broken land lines, as the fault makes no connection with the earth to complete the circuit.

521. **The Electro-Magnet.**—We have seen that electric currents turn magnetic needles at right angles to the direc-

FIG. 272.—ELECTRO-MAGNET.

tion in which they flow. They do more. If made to flow across bars of iron or steel, they magnetize them. If the bar is of *iron*, it is *magnetic* only while the current flows. A magnet of this kind is an *electro-magnet*.

522. **The Helix.**—A current crossing an iron bar only once, makes a very feeble magnet of it. If the conducting wire be coated with an insulating cover of wax, india-rubber, silk, or even cotton, it may be wound many times around a bar, as cotton is wound on a spool. As many currents multiply the effect of one, there is scarcely a limit to the power of electro-magnets thus made. Fig. 272 shows a horseshoe electro-magnet. A layer of wire wound from end to end or over a considerable part of the length of a

FIG. 273.—MAGNETIZING STEEL BAR.

bar is called a *helix*. Several layers, such as are shown on each arm of the horseshoe in the figure, constitute a *coil*.

Experiment 179.—Procure of a dealer from two to four ounces of very fine covered copper wire. Wind it neatly around an iron bar as large as an ordinary lead-pencil, making several layers. Connect the free ends of the wire with any simple battery, and experiment with the electro-magnet thus formed. Dip it into nails, and, when it is loaded, break the circuit. Notice that some of the nails incline to stay on after the current is stopped. This is on account of the residual magnetism which iron is apt to exhibit after having been once magnetized. Try the poles of the electro-magnet with a magnetic needle, and notice the direction of winding of the coil of wire as looked at from each end. Refer to rule for deflection of needle by the electric current, and notice that the same rule holds here.

As electro-magnets are much more powerful than steel magnets, they are mostly used in magnetizing steel bars. Fig. 273 shows the method of operation. Of course, reference to the direction of winding *indicates* the respective poles of the electro-magnet.

523. The Helix a Magnet.—A helix, or coil carrying a voltaic current, not only communicates magnetic properties to the bar of iron in the middle, or "core," but is itself a magnet. It attracts iron, is attracted and repelled at the different ends by the poles of a steel magnet, and, if properly suspended, arranges itself in the magnetic meridian, the hollow centre taking the north-and-south direction. If a strong steel magnet be placed directly under a helix suspended horizontally, the helix assumes the direction of the length of the magnet, the convolutions of the wire being *across* its length. This shows a *mutual action* between electric currents and magnets, and that they are naturally at right angles to each other.

524. Electric Currents in the Earth.—The north-and-south tendency of magnets may be due to electric currents flowing westward around the earth. In cases of unusual fluctuation of the compass, electric currents have frequently been detected in such direction as they should flow to account for some of the observed phenomena. The existence of currents to account for all the ordinary phenomena of the magnetic needle is not established, but there are strong reasons for believing that they exist.

525. Magnetic Storms.—Telegraph-operators frequently report electrical or "magnetic storms," which are sometimes of considerable extent and cause them much inconvenience. They are not necessarily accompanied by wind, rain, snow, or any other of the phenomena ordinarily included in the term "storm," but are simply disturbances in the electrical or magnetic condition of the earth and the air. Magnetic needles move backward and forward through several degrees, telegraph-wires refuse to carry the battery currents with any regularity, and fine displays of aurora borealis are witnessed.[1] In the fall of 1882, telegraphic communication in Canada and the Northern United States was interrupted for several days by one of these storms. Sometimes signals could not be sent, and sometimes they were sent without a battery. All lines worked better by using a wire in each direction instead of "grounding" at the ends. (See Art. 530.)

[1] Some connection seems to exist between these storms and the condition of the *sun*. (See Sharpless and Philips's Astronomy, p. 58.)

526. **Applications of Electro-Magnetism.**—Electro-magnets are extensively used in the many forms of dynamo, electric motor, etc., which are rapidly coming into use. The current for these is developed by induction, to be studied later.

527. **The Electric Telegraph.**—The first useful and economical application of the electro-magnet was in telegraphing, and in that the battery is still largely used to furnish the current. The word "telegraphing" means writing at a great distance, and a "telegraph" is any instrument by which a person at one place can make signs which may be read at another place some distance away.

528. **History of the Telegraph.**—Frictional electricity was known to the ancients before the Christian era, but conduction and insulation appear not to have been discovered till 1729. Very soon after the discovery of conduction, and the classification of bodies as conductors and insulators, plans were devised for carrying conducting wires on insulating supports and transmitting through them charges of frictional electricity, which should be sent in an order agreed upon to represent letters or words. Systems arranged on this principle were never very satisfactory. One of the best employed a separate wire for each letter of the alphabet, each wire being supplied with a delicate electroscope. The person sending the message touched the wires to the conductor of an electrical machine in such order as to spell out the message to be transmitted, and the person receiving it watched the order of divergence in the electroscopes, and so read the message. This system was costly and cumbrous, and it could be successfully operated only through short distances (20 or 30 miles), so that it never came into general use.

Voltaic electricity was discovered about 1792. Oersted's discovery of the deflection of the magnetic needle was made in 1820, and was soon applied by Wheatstone[1] and others to successful systems of telegraphing.

529. **The Morse Telegraph.**—The introduction of the electro-magnet as an essential feature of the telegraph dates back to about

[1] Charles Wheatstone, English, 1802–1875, professor at King's College, London.

1836, when Samuel F. B. Morse[1] invented the electro-magnetic telegraph now in general use in civilized countries. His original device consisted of a register (Fig. 274) for receiving the message, and a key (see Fig. 275) for transmitting it. The register is easily understood from the figure. The current from the line wire passes through the coils of the electro-magnet, which is thus rendered magnetic, and draws down the armature. This elevates the point shown on the opposite end of the lever. The paper is drawn at a uniform rate between the rollers by the action of the weight under the table. When the point is pressed against the paper, it describes a straight line, whose length is proportional to the time the point is held there. This is

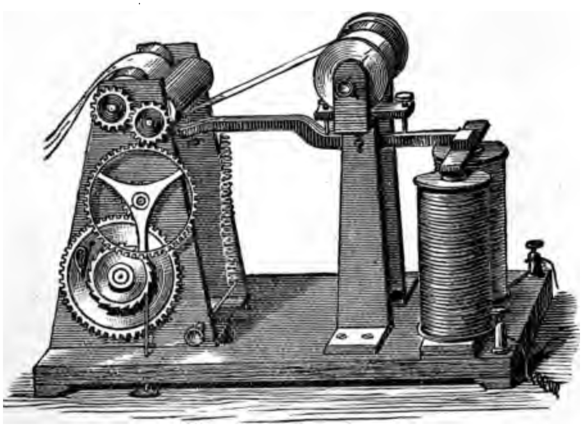

FIG. 274.—TELEGRAPH-REGISTER.

determined by the operator at the distant station, who alternately depresses and elevates his key. While he holds the key down the current passes, the armature is held down, and the point is pressed up. Long and short dashes (called respectively "dashes" and "dots") and vacant spaces are thus recorded in succession on the strip of paper, and, as a definite group of these dots and dashes represents each letter, figure, and other mark used, the receiving operator is able to interpret them. The accompanying line of dashes and hyphens represents the appearance of such a message. The letters above them

[1] American, 1791–1872. The inventor of the form of telegraph-receiver in common use.

are intended as a translation, for the benefit of the readers of this book.

W i l l   c o m e   a t   t e n   A M   .

.-- .. — —   .. . . . -- .   .- -   - . -.   .- -- --   ..--..

The striking of the lever against the screws which regulate the distance of its motion makes an appreciable sound, and a certain different combination of these is used to call the attention of each particular operator on a given line.

Soon after this system came into use, operators discovered that they could read the *messages* as well as the office-call by the click of the lever against the screws, and the paper was dispensed with. A new form of instrument, known as the *sounder*, now takes the place of the register in most telegraph-offices. Its general structure may be understood from Fig. 275.

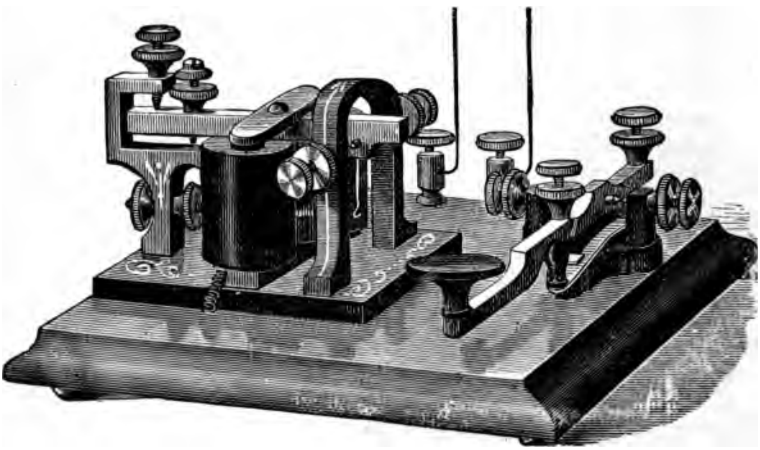

FIG. 275.—TELEGRAPH SOUNDER AND KEY.

The lever is drawn down by the electro-magnet, and strikes against a solid metal piece, making a loud sound. A spring is so attached to an arm connected with the lever that it instantly raises the lever on the breaking of the current.

When a telegraph line is long, the resistance of the wire renders the current feeble, so that the sounder is not operated with sufficient force to be satisfactory under all circumstances. To remedy this, a *local battery* is introduced at each station to operate the sounder at

that station. The circuit of this battery (the "local circuit") is opened and closed by a *relay*, which in turn is operated by the feeble current of the line-wire. The "relay" is a very delicate electro-magnet, operating a lever whose end is made to strike against a metal piece and thus close the local circuit.

Fig. 276 represents, in vertical section, a Morse telegraph-station, such as may be seen in almost any town or at almost any railroad-station. The student will please trace out the office and action of each piece of apparatus. The key, the sounder, and the relay may be supposed on a table, and the local battery under it. The wire of the main line is seen entering at one side and leaving at the other. The key must be kept "closed" at all times, except in the particular office on a line from which a message is, at the time, being sent. The current in Fig. 276 we will suppose enters at the left, passes through the key, and by the wire to the relay, around the coils of the electro-magnet in the relay, and out at the right, going in the same way *through all the offices which are in the main-line circuit*. When no message is traversing the line, the current is continuous, the cores of all the relays are magnets, and the armatures are all held against the opposing anvils. This closes the local circuits and holds down the levers of the sounders. When a message is to be sent from any office on the line to any other office, the operator in the sending office opens his key. This breaks the circuit, stops the current, and demagnetizes the relay, whose spring pulls back the armature. This in turn breaks the local circuit and demagnetizes the sounder, whose lever is raised by its spring. This is the condition of things shown in the figure.

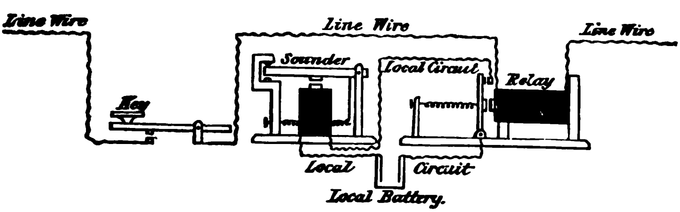

FIG. 276.—DIAGRAM OF MORSE TELEGRAPH STATION.

The sender then operates his key by pressing it down and raising it at certain intervals. The currents thus sent operate on the relay situated in each office of the line, and its armature vibrates, keeping time with the motions of the sender's key. This acts as a key for the local circuit, and a succession of currents is sent through it, operating the sounder. *Thus it will* be seen that a message sent from any one

station to any other station may be read at all the stations in the main circuit. The sending operator even reads his own message.

530. The Earth used as a Conductor.—In all ordinary telegraph and telephone lines the earth is used as a conductor in one direction, and but one wire is employed. Most lines of telegraph have a battery at each end, the positive electrode of one battery and the negative of the other being connected with the same wire. The other electrode of each battery is connected with a "ground-wire," which is attached to a metallic plate buried in moist earth.

531. Simultaneous Telegrams.—The simple Morse system just described is very reliable, but by it a given wire can transmit only one message at a time. Various arrangements are now in use by which a single wire may be used to convey several messages at the same time—some in one direction and some in the other—without conflict. *Duplex telegraphy* is the sending of *two* messages, one each way;

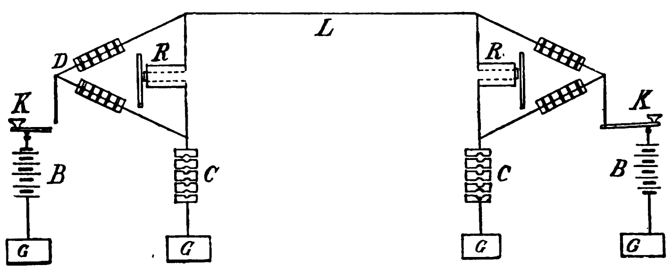

FIG. 277.—CIRCUIT FOR DUPLEX TELEGRAPHY.

and *quadruplex telegraphy* is the sending of *four* messages, two each way, at the same time. There are, also, working systems of *multiplex* telegraphy, by which any desired number of messages may be transmitted simultaneously over a single wire.

532. Duplex Telegraphy.—Of the various duplex telegraphs, one only, the "bridge duplex," can be mentioned here. The object is for the relay at either end to be operated only by the key at the *opposite* end. By referring to Fig. 277, the essential features may be gathered. The diagram represents two stations exactly similar, and connected by the line L. The current from the battery B is divided

at D, one part going over the line L and the other part, by way of the resistance coils C, to the ground at G. The resistance of C is adjusted exactly equal to that of the line L, and the relay at the other end. When this is the case, *no* current from B flows over the bridge R, so that K may be operated without actuating the relay R. Currents from the battery at the *other end*, however, pass over the bridge through R, and so to earth. Thus the operator K *receives* a message from the line, though his assistant may be *sending* one at the same time. The other arms of the bridge contain balanced resistance coils, together greater than C, to insure that the incoming current will pass through R even when K is closed. The local battery and register, or sounder, are the same as in a simple Morse office.

533. Quadruplex Telegraphy.—One of the most successful quadruplex systems of telegraphy employs, as a new feature, the

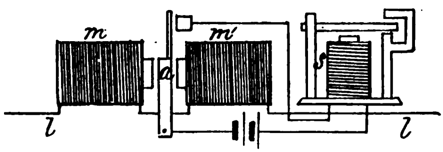

FIG. 278.—SOUNDER WITH POLARIZED RELAY.

"polarized" relay. The figure shows how it works. The two parts of the electro-magnet *mm′* face each other, and the armature *a* is a *steel magnet* with one of its poles between the poles of the electro-magnet. When a current passes through the line *l* in one direction, the armature will be attracted by *m′*, close the local circuit and actuate the sounder *s*. When a current passes in the *other* direction through the line, the armature will be attracted by *m*, thus opening the local circuit. The key which works the line for this relay *reverses* the current instead of simply opening and closing it,—*i.e.*, when *pressed down* it connects the *carbon* with the line wire, and when *up*, it connects the *zinc* with the line.

The bridge described in the last article is used in the quadruplex, but contains *two* relays instead of one,—a *polarized* relay and an *ordinary* relay. The ordinary relay has its spring so adjusted that a certain *strength of current* is required to move the armature. Two batteries are connected with the line, the *stronger* by an ordinary key, and *both* by a pole-changing key. It is important to remember that in bridge telegraphing the ordinary key is *open* when not in use. The pole-changing key is always closed. If the pole-changing key alone

is worked, it actuates only the polarized relay at the other end, the current being too weak for the spring of the ordinary relay. If the ordinary key is worked, it actuates only the ordinary relay at the other end, the polarized relay requiring reversal of current. When both are worked at once, the polarized relay answers to the change of current, and the ordinary relay to the current from the strong battery. The bridge performs the same office as in the duplex.

The art of telegraphy is advancing very rapidly. Mechanical arrangements for transmitting are successfully employed, and automatic arrangements for receiving and for retransmitting if desired. The simple Morse system was a marvel of completeness and rapidity. A good operator can send or receive 30 or 40 words per minute,—as fast as a rapid penman can write. This was the capacity of a single wire until recently. With a combination of the latest inventions the feat has been accomplished of transmitting 1500 words between New York and Boston over the same wire in one minute.

534. **Ocean Cables.**—On land lines the line-wire, even if very long, is charged and discharged nearly instantly, and the current is no appreciable length of time in traversing it. Ocean cables, being laid under water, must be surrounded by an insulator. Gutta-percha is used. The arrangement then resembles a Leyden jar, the conducting wire representing the inside coat, and the water the outside coat, while the gutta-percha acts as the glass. To *charge* this requires some time, and to discharge it requires as long. In the cable between Ireland and Newfoundland this amounts to a total of six seconds. On this account special instruments are required for sending and receiving messages over ocean cables.

535. **Electric Clocks.**—The electric current is frequently used to propel or regulate clocks. The pendulum of a standard clock is made to operate a key, which opens and closes a circuit including all the clocks to be regulated. These may be distributed over a large building, or a town, or along a railroad line. The interrupted current passes through an electro-magnet in each clock. The armature, moving in exact unison with the beats of the standard clock, either operates on a ratchet-wheel and communicates motion to the clock, or regulates the swinging of a pendulum. In either case all the clocks will keep exactly together and with the regulator.

536. **Thermal Electricity.**—If a bar of antimony (A, Fig. 279) and a bar of bismuth, B, be soldered together at one *end, and* the junction be moderately heated, wires at the

other end being connected with the coils of a galvanometer, an electric current is found to exist, flowing from the antimony through the wire to the bismuth, and from the bismuth across the heated junction to the antimony. If the junction be cooled instead of being heated, a current is established in the opposite direction.

If a large number of such bars be joined together in series, as shown in Fig. 280, a very slight amount of heating or cooling of the

FIG. 279.—THERMO-ELECTRIC PAIR.

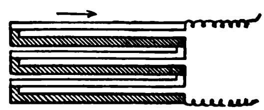

FIG. 280.—PRINCIPLE OF THERMOPILE.

junctions at one end makes an appreciable current, the current always flowing at the warmer junctions from bismuth to antimony, and at the cooler from antimony to bismuth. The same effect, in a less degree, is produced by substituting other metals for the antimony and bismuth. Two metals so arranged are called a thermo-electric pair, and a combination of several (usually twenty-five to one hundred) such pairs constitutes a *thermopile*. When connected with a galvanometer it is known as the *thermo-multiplier*, one of the most delicate of thermometers.

The heat being converted directly into current in thermo-electric couples, without the loss experienced in steam-engines, points to the possibility that we may some day learn to develop in this way the most economical currents for electric lighting, electric motors, etc. Some progress has been made by Edison and others in this direction, but much success has not been achieved.

537. Induced Currents.—If a coil of wire, around which a battery current is flowing, be introduced into a larger coil (see Fig. 281), a galvanometer shows that *while the first coil is moving into the second* a current flows in the outside coil. On *removing* the inside coil, a current flows in the outside coil. This is an *induced* current, and it *lasts only while one coil moves towards or from the other*. The coil connected with the battery is called the *primary* coil, and the other the *secondary* coil. Every motion of the primary coil *towards* or *into* the secondary coil produces a current

in the secondary coil; and every motion of the primary *from* or *out of* the secondary produces a current in the

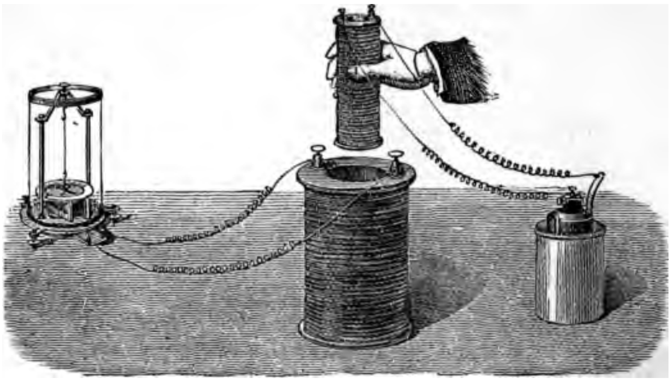

FIG. 281.—PRIMARY AND SECONDARY CURRENTS.

secondary; but the two currents thus produced are *opposite in direction.*

If the primary coil be placed stationary, inside the secondary, any *increase or decrease in the strength of the primary current* induces a current in the secondary, the two currents thus induced being opposite in direction.

If the primary circuit be alternately *opened* and *closed. momentary* currents are induced in the secondary. These currents have great electro-motive force, will jump through air, and readily produce a static charge in a condenser.

538. **Direction of Induced Currents.**—In the three cases above given, the currents induced by *opening* the primary circuit, by *weakening* the primary current, and by *withdrawing* the primary coil, are *direct* currents,—*i.e.*, their direction is the same as that of the primary; while the currents induced by *closing*, *strengthening*, or *approaching* the primary are *inverse*,—*i.e.*, they flow *backward* with reference to the direction of the primary.

539. **The Ruhmkorff Induction-Coil.**—This is a device for

producing induced currents by the opening and closing of a primary circuit. Fig. 282 gives a general view of Queen's "dissected" Ruhmkorff coil. The battery current enters by one of the binding-posts AA′, and leaves by the other. C is the commutator for reversing the current so that it may be made to flow either way, at pleasure, through the primary coil. The primary coil surrounds the iron *core r*. The secondary, surrounding this, ends at the terminals BB′. The primary

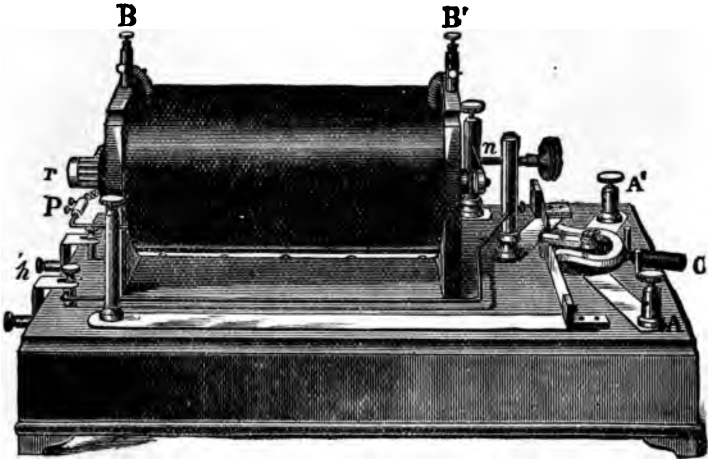

FIG. 282.—RUHMKORFF'S INDUCTION-COIL.

circuit is automatically closed and opened by the "break" *n*. It works thus: the current must pass through the spring *n*. As it passes it magnetizes the core which is seen projecting at the right. This *attracts* the circular disk on *n*, drawing the spring away from the screw shown, and thus *breaking the circuit.* This demagnetizes the core, the disk on *n* is released, *n* flies back and makes the circuit again, the operation being repeated rapidly or slowly, depending on the distance *n* has to move.

The *direct* current, which, as stated, is that induced on the *breaking* of the primary circuit, is the current used in experiments with the Ruhmkorff coil. To give this its best effect, the break must be as nearly instantaneous as possible. The E. M. F. of the secondary current increases with the number of layers of the wire in the secondary coil. The coil is discharged between the posts B and B′, through any partial conductor placed in its path, even piercing paper, leather, and glass, and giving shocks such as are experienced from the Leyden jar.

540. Geissler Tubes.—One of the most interesting and instructive lines of experiments with the Ruhmkorff coil consists in discharging it through glass tubes which have been exhausted of most of their gaseous contents. In Art. 472 it was stated that the electrical discharge, though taking place with difficulty through ordinary air, takes place quite readily through highly-rarefied air. The same is true for other gases. If a glass tube be filled with air, hydrogen, oxygen, nitrogen, carbonic acid, or any other gas, and then by means of an air-pump most of the gas be taken out, the passage of the Ruhmkorff discharge through the remaining rarefied gas fills the tube with a glow of light. This light is differently colored for different gases. The color in each case is that which is due to the incandescence of that particular gas. (Art. 467.) The contents of such a tube may thus be accurately determined by discharging an induction-coil through it and examining the discharge with a spectroscope.

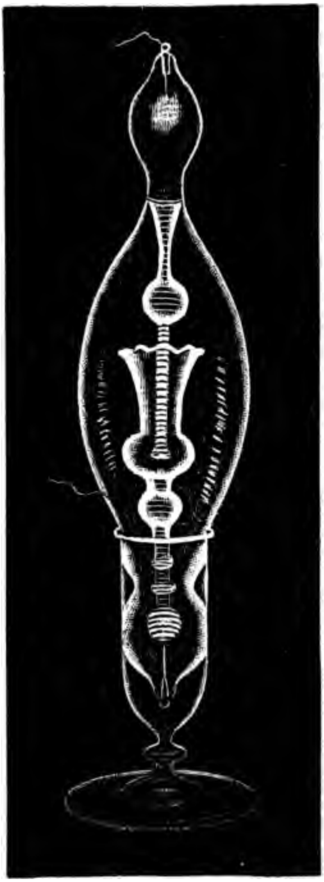

FIG. 283.—GEISSLER TUBE.

Many beautiful designs of such exhausted tubes, *Geissler tubes*, are in the market, and they may generally be made to operate with quite small Ruhmkorff coils. Fig. 283 gives an imperfect idea of the discharge through a Geissler tube in a dark room. The tube is supported by being stood upright in a glass vase. At the two extremities are platinum wires, sealed into the glass and connected with the terminals of the Ruhmkorff coil. The glass vase and bulbs inside the tube are colored with oxide of

uranium, which possesses in a remarkable degree the power of fluorescence when illuminated by the electric spark. The vase at the bottom is filled with a solution of sulphate of quinine, which exhibits a similar property. The uranium fluorescence should be a light green, the quinine a soft blue. The violet light in the rest of the tube is due to nitrogen or air.

541. **Magneto-Electric Currents.**—If, instead of a primary coil, a *magnet* be used in connection with a secondary coil, its approach induces a current in one direction, and its removal induces a current in the opposite direction. If an iron core be placed in the secondary (Fig. 284), opposite

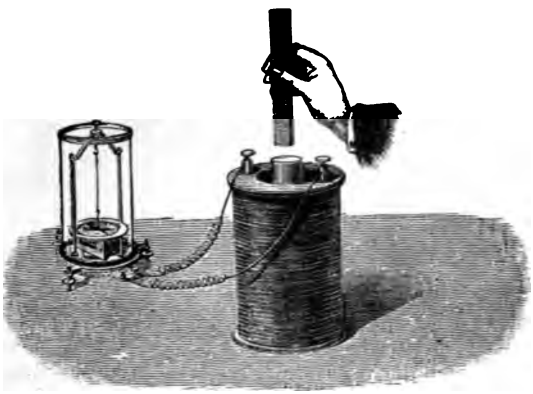

FIG. 284.—CURRENT INDUCED BY MAGNET.

and *stronger* currents are induced by the approach or withdrawal of either pole of the magnet.

If now the magnet be placed in the coil, and the iron be suddenly moved towards it and away from it, similar alternating currents will be induced. The iron in this case is a magnet by induction (Art. 418), and the effect of its motion to and fro is to strengthen and weaken the poles of the steel magnet. It is this *strengthening and weakening of the magnet-poles that gives rise to the currents.* If these currents, instead of being passed through a galvanometer, as shown in Fig. 284, be passed through a second coil surrounding a

magnet, they vary the strength of the magnet, the current in one direction adding to its strength, on the principle of the electro-magnet, and that in the other direction taking from it.

542. **The Bell Telephone.**—The last article explains the principle of the Bell telephone, the first of the many American speaking-telephones to come into public notice. Fig. 285 shows the instrument in section. NS is the steel magnet, B is the coil of wire whose ends connect with the line at CC, and LL is the iron whose motion towards and from the magnet causes the currents in the line wire. The iron

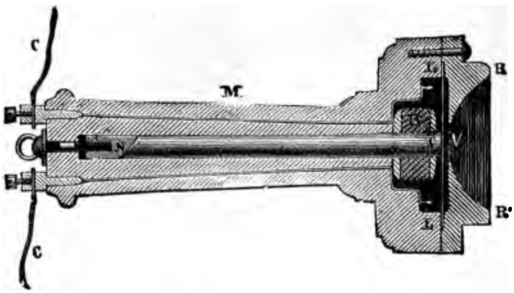

FIG. 285.—SECTION OF BELL TELEPHONE.

LL is a thin sheet or "diaphragm," which is set into vibration by the sound-waves of the sender's voice in RR′V. Thus the electric currents sent through the line agree in frequency with the vibrations of the speaker's voice. These currents are received at the distant station by an exactly similar instrument, and passing through the coil B alternately strengthen and weaken the magnet-pole S. This causes S

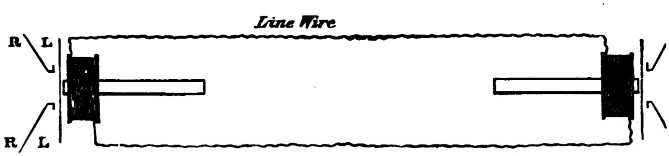

FIG. 286.—DIAGRAM OF BELL TELEPHONE LINE.

to exert a varying attraction on the diaphragm, which is thus set into vibration, the vibrations agreeing in rapidity, through the action of the varying currents, with the rapidity of the sending diaphragm, which represents the sound-waves of the sender's voice. Fig. 286 is

an ideal section of a Bell telephone circuit, R and L representing the same parts as in Fig. 285.

In recent practice the Bell telephone is used only as a receiver. As a transmitter its currents are weak, and not adapted to long distances. The American Bell Telephone Company uses transmitters varying somewhat in construction, but all combinations of various devices of Edison, Blake, Berliner, and others. These are all one form or other of

543. The Carbon Transmitter.—Various substances, soft in texture and rather poor conductors of electricity, have their conductivity increased by pressure, and it varies under varying pressure. The best substance to illustrate this is lampblack, made coherent by some kind of glue. If in Fig. 287 the current from the battery B pass through the carbon "button" C, and so around the short circuit, including the galvanometer G, it is found that the amount of deflection of G is exactly proportional to the amount of weight upon C.

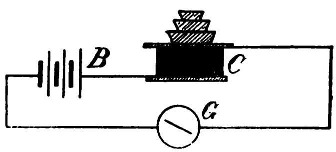

FIG. 287.—CARBON BUTTON.

If the apparatus of Fig. 287 be set vertically, and sound vibrations be substituted for the metal weights to vary the pressure on the carbon button, we have the essential features of the transmitter. In the diagram (Fig. 288) the words are spoken at R, the metal plate vibrates and varies the pressure on C. The varying current from the battery B is passed through the primary of the induction-coil I, and the secondary of this coil connects with the line at LL.

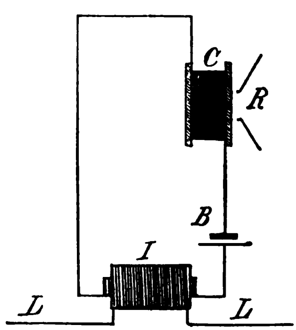

FIG. 288.—CARBON TRANSMITTER.

544. There may be any number of receivers (Art. 542) in the line

circuit, and any number of transmitting stations on the same line. As now used, however, the telephones of a certain town all connect with a central station, where at the call of a bell the attendant puts any subscriber in connection with any other one, by simply joining their wires together with a plug-switch.

545. The Alarm-Bell.—The attention of the receiving operator of a telephone message is called by a bell similar to those employed in burglar- and fire-alarms, and in hotels and other large buildings

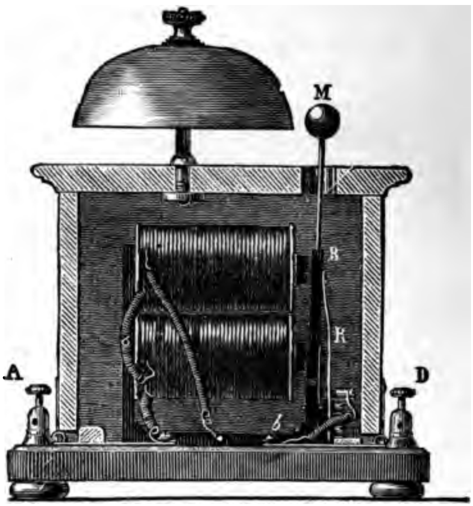

FIG. 289.—ELECTRIC BELL.

as call-bells. The operation of such a bell will be readily understood from Fig. 289. The current passes in at one of the "binding screws," AD, and out at the other, traversing the coils of the electro-magnet. The core is thus rendered magnetic, and the armature, B, is drawn forward, causing the hammer, M, to strike the bell. The current on its way from A to D passes up through the armature, B, and down through the spring, R. When B is drawn forward, contact with the spring, R, is broken, and the current ceases. The core is thus demagnetized, and B is released and thrown back by the small spring at the bottom. This again closes the circuit, and the operation is repeated, in most cases several times in a second, as long as the current is sent.

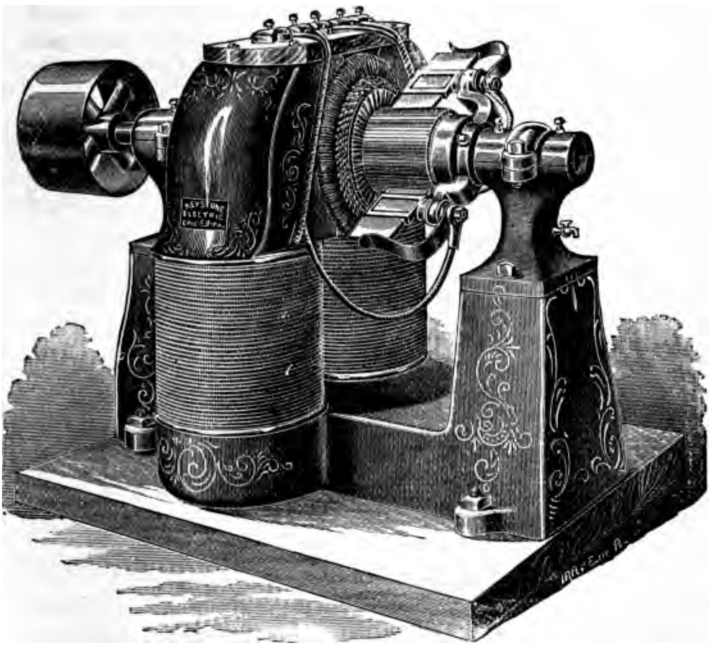

FIG. 290.—KEYSTONE REVERSIBLE MOTOR.

IV.—DYNAMO-ELECTRIC GENERATORS AND ELECTRIC MOTORS.

546. **Principle of the Dynamo.**—If a conducting-wire, or any conductor, be moved in a magnetic field so as to *cross the lines of magnetic force*, a difference of potential is induced in the two ends of the moving conductor, and a current of electricity will flow through a circuit connecting them. These currents are *magneto-electric* currents, of the class defined in Arts. 537 and 541, but as they are so extensively produced by dynamo-electric machines (properly "generators"), the study of them was reserved for this section. A dynamo-current means a current made by the *expenditure of power*, and the machine for producing it

is called by various names, which mostly contract into "dynamo."

Experiment 180.—The principle stated in the first sentence above may be illustrated by the apparatus shown in Fig. 291. A coil of fine insulated wire, C, is suddenly thrust down between the poles of the

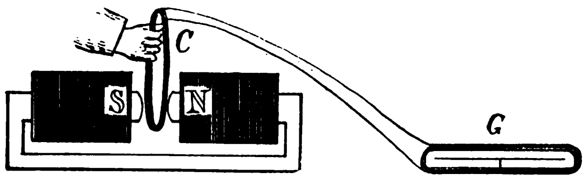

FIG. 291.—PRINCIPLE OF DYNAMO.

strong electro-magnet, NS. The galvanometer G is in circuit with the coil C, and its needle is suddenly deflected, soon coming to rest again where it started. If now the coil be suddenly *withdrawn* from between the poles, the needle is again deflected for the moment, but in the *opposite direction*. The lines of force in this figure extend practically straight from N to S, and the experiment shows that a current is produced by cutting the lines of force with the wire, and that the direction of the current depends on the direction of motion of the wire.

547. **The Direction of the Currents** may be gathered from Fig. 292. The wire, or coil of wire, is rotated, as indicated by the curved arrow, between the poles of the magnet. While the wire moves *down* it cuts the lines of force in one direction, and while it moves

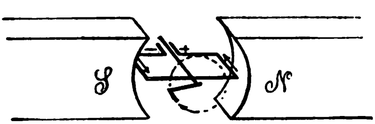

FIG. 292.—DIRECTION OF DYNAMO CURRENT.

up, it cuts them in the other direction. These two *unite* in the wire and tend to make a current flowing in the direction of the straight arrows. The terminals + and — of the wire would be the positive and negative poles of this simple dynamo. If the motion of the handle be reversed, the current is reversed. If a man in miniature be imagined carrying in front of him by both hands the wire in which the current is induced, when he walks on the *north pole of the* magnet the current enters at his *left* hand, and when

he walks on the *south pole* the current enters at his *right* hand.

548. **The Alternating Current.**—If the wires marked + and — in Fig. 292 were attached each to one end of an external circuit,—which is accomplished by having each attached to a ring which rotates with it and rubs against a suitable metallic "brush,"—it is evident that as the right-hand end of the coil reached the bottom part of its turn and began to ascend in front of S, the direction of the current in it would be reversed. At the same instant, for a similar reason, the direction of the current in the other half would be reversed. The current in the *whole circuit*, of whatever extent, would then be reversed twice in each revolution of the coil. This is the principle of the "alternating-current" dynamo which is extensively used for some purposes. (Art. 561.)

549. **The Commutator.**—For most purposes it is desirable that the current should flow all the time in the *same direction* in the external circuit. This is accomplished by the commutator, the principle of which is indicated in Fig. 293. The rotation is as shown by the arrow on the driving-belt. The commutator is at *c*. It consists of a metallic drum cut in half, and having the two halves insulated. One end of the coil of wire is attached to each section of this drum. The "brushes," *b*, are metallic springs which rub against the commutator as it revolves and take away the electricity. They are so adjusted that at the instant when the coil is vertical and about to reverse, the parts of the commutator come into contact each with the *other* brush,—*i.e.*, the brushes are made to *jump the breaks*. Of course this keeps the positive potential always at +, and the negative always at —.

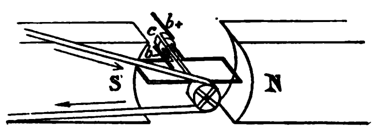

FIG. 293.—SIMPLE COMMUTATOR.

550. **Parts of the Dynamo.**—The simple diagrams above

v

shown indicate the essential parts of an actual dynamo. The large magnet is the "Field-Magnet." It is a powerful electro-magnet generally excited by the dynamo itself. As an alternating current would not produce permanent polarity in the electro-magnet, some alternating-current dynamos have separate continuous-current dynamos to excite the field-magnets.

The simple circle of wire would produce comparatively feeble currents. In most machines there are many coils wound on a ring, drum, disk, or core of some kind. The revolving coils taken together constitute the "armature."

In Fig. 294 the armature is shown at C, and the field-magnet at M. The "Commutator" and "Brush" of an actual dynamo are named in

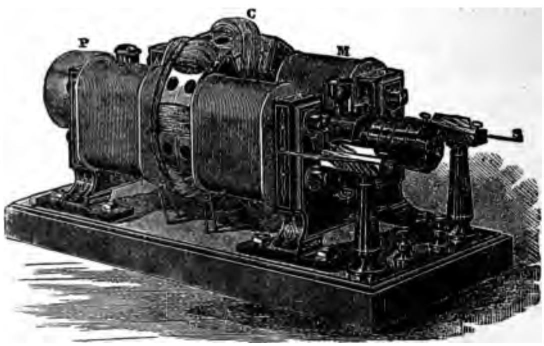

FIG. 294.—BRUSH'S DYNAMO-ELECTRIC MACHINE.

the descriptions of the diagrams. In Fig. 294 the four-part radiated wheel at the right is the commutator and the springs SS are the brushes. P is the driving-pulley.

It is well known that there are a hundred or more styles of dynamos in successful operation. Some of these are built for *special* results, some for general excellence and economy. A few leading principles only, in structure and operation, are here treated of.

The field-magnet should be strong, so that it will give a field of great intensity,—*i.e.*, with a large "number" of lines of force (see Art. 421) to a given area. This is accomplished by having massive

soft-iron cores, surrounded by large coils of wire, with a strong current flowing through it.

551. Exciting the Field-Magnet.—The first magneto-electric machines consisted of armatures revolved between the poles of a permanent steel magnet. The discovery of the principle involved was made in 1831 by Faraday, who by using a large number of magnets constructed a machine for light-house illumination. In 1866, Wilde used the current from such a machine to excite electro-magnets of a more powerful machine. The modern dynamo excites its own field-magnets. The principle first involved is, that an electro-magnet once excited retains ever afterwards a small

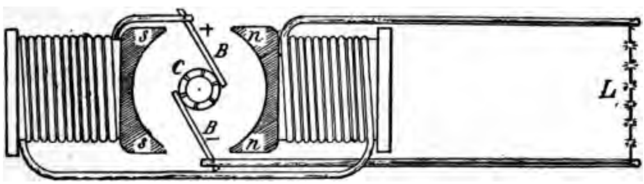

FIG. 295.—SERIES DYNAMO AND SERIES ARC LIGHTS.

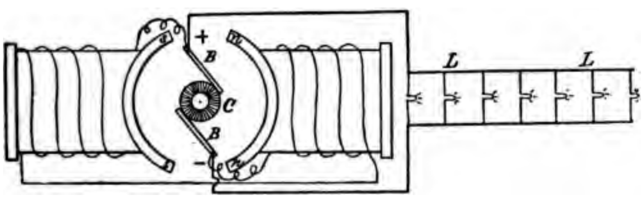

FIG. 296.—SHUNT-DYNAMO AND PARALLEL INCANDESCENT LAMPS.

amount of "residual" magnetism. When the armature begins to revolve the lines of force are cut, and a weak current flows around the field-magnet. This strengthens the magnet, which makes more lines of force, more E. M. F. (Art. 556), and more current. This current may be all passed around the field-magnet or not, depending upon

552. The Field-Magnet Circuit.—In some dynamos, notably those for maintaining a number of arc lights (Art. 558) in series, the field-magnets are "wound in series,"—that is

they are placed in the external circuit *with the lamps*, so that all the current generated by the machine passes through them. For many purposes, notably for maintaining a large number of incandescent lamps in parallel circuit, a "shunt-winding" is preferable; while in some cases a combination of the two, forming a "compound winding," is successfully used.

553. The two methods of winding, also the two systems of lamp circuit, are shown in Figs. 295 and 296. The series machine with series lamps is hard to maintain at constant potential, some form of regulator being required. Throwing additional lamps into action increases the resistance of the circuit, and thus *decreases the current*. The shunt-dynamo with parallel lamps is theoretically perfectly regulating, and would be exactly so but for the resistance of the armature and of the leads, or "mains."

554. **The Armature** varies in construction, depending on its purpose. The coils of wire may be connected in series or in parallel

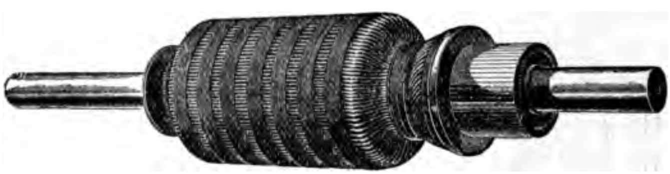

FIG. 297.—EDISON ARMATURE.

arc, as battery cells may. If many wires are employed, each one with its two ends attached to opposite sides of the commutator, it is similar to a battery connected in parallel circuit; a large amount of current gets to the brushes, even with a low E. M. F., because of the small resistance of the many wires. If, however, each coil of wire is composed of many turns of the same continuous wire, it is like a battery connected in series: the current of one turn is sent through the next, this through the third, and so on, the E. M. F. of a hundred turns of wire being a hundred times as great as that of one turn.

The armature should move as close as possible to the poles of the magnets, to use the greatest intensity of field.

555. **The Commutator,** instead of being in two parts as shown

in the diagram, Fig. 293, generally has one segment for each coil, and these are made into the form of a cylinder, but insulated from each other. There are about four segments in the commutator of the Brush machine series connected, shown in Fig. 294, and about sixty-four in the Edison armature connected in parallel, shown in Fig. 297.

556. **The Speed of Rotation.**—After a self-exciting dynamo is constructed, the E. M. F. of the current derived from it depends largely upon the speed of rotation. *The E. M. F. is directly proportional to the number of lines of force cut in a second*, and in a field of uniform and constant intensity, this depends upon velocity alone.

The speed of rotation in different dynamos varies greatly, but it is always high. A Thomson-Houston dynamo shunt-wound for incandescent lighting makes about 1300 revolutions per minute for a current of 80 volts. A dynamo by the same firm series-wound for arc lighting (Art. 558) has a much more intense field, and gives a current of 3000 volts when running at 850 revolutions per minute.

557. **The Absolute Units of Electrical Measurement.**—The last article brings us to the *origin* of the practical units defined in Arts. 503–5, and all others derived from them. These practical units are all derived from a system of *absolute C. G. S. units* inconveniently small (or large) in themselves for the engineer, who, therefore, uses *multiples* (or parts) of them.

The *absolute unit of electro-motive force* is the electro-motive force induced in a conductor which moves in a magnetic field so as to cut *one line of force per second.* The volt is 100,000,000 (usually written 10^8) of these absolute units.

The absolute unit of current is the current which, flowing around a circle of *one centimetre radius, exerts a force of one dyne on a unit magnet-pole placed at its centre.* The ampere is $\frac{1}{10}$ of the absolute unit of current.

The absolute unit of resistance is the resistance *through which the unit of E. M. F. can maintain a unit of current.* By Ohm's law, $C = \frac{E}{R}$, or $R = \frac{E}{C}$. Working out this equation with the above values of volt and ampere, we find that the ohm is 1,000,000,000, or 10^9 absolute units of resistance.

558. **The Arc Light.**—One of the most manifest uses of the dynamo is the production of a current for electric lighting. The incandescent lamp has been sufficiently described.

It requires a current of from 75 to 80 volts. The resistance of a good table-lamp is from 100 to 160 ohms. The intensely bright electric light used for street illumination, for large stores, depots, etc., is the "arc" light. To produce the arc light, the wires from the dynamo are attached each to a pencil of carbon, artificially prepared and coated on the outside with a conducting material. When these carbons in contact are made part of a circuit, the current may pass invisibly from one to the other. If, however, they are slightly drawn apart with a current of 1000 volts passing through them, the current carries some carbon across the break in an intensely luminous bridge, and thus keeps up for itself a passage. This generally assumes a crescent shape, hence the name. The heat in the electric arc is intense, fusing any of the metals instantly. Lights of from 1000 to 30,000 candle-power, or more, may be maintained by this means.

559. **Regulation of Arc Light.**—The carbons of the arc light gradually wear away, partly burned and partly scattered in fine particles. The arc thus grows longer. The resistance of the arc is always high, and it increases with the length. The effect of the shortening of the carbons would be to so increase the resistance that the current flowing would become too small to maintain the light. Many ingenious devices have been used to keep the carbons at a constant distance apart. One of the most simple and effective is illustrated in

560. **The Brush Arc Lamp.**—This is best described by reference to the figure (298). The light is produced in the space between the two carbons, *kk*. The current enters by the coil *a*, then goes to the sliding rod *f*, which holds one carbon at its lower extremity. Thence it passes through the lower carbon and out at *y*. When the current starts, the carbons are in contact. The current magnetizes the iron core *d* and draws it into the coil, thus separating the carbons. As the distance between them increases, the *resistance* rises, thus lessening the amount of current and the consequent attraction of the coil for the core. Thus the point is reached at which a steady arc is *maintained.*

561. Alternating Currents and Transformers.—The simple dynamo first described, without a commutator, would give an alternating current. The same result is obtained in other and better ways, and there are now many patterns of alternating-current dynamos. Alternating currents may be used for incandescent and arc lighting, and for some other purposes in which reversal of polarity is no disadvantage. An alternating current used with a "transformer" has a special field. A transformer is simply an induction-coil, and in that a *continuous* current could induce no secondary current. (Art. 537.) By this combination a current of low potential may be carried safely to its place of destination, and there induce currents of high potential for arc lighting; or a current of high potential may be carried a long distance through a fine wire, and then induce currents of low potential for incandescent lights. In the latter case the secondary coil of the transformer consists of a few coils of heavy wire.

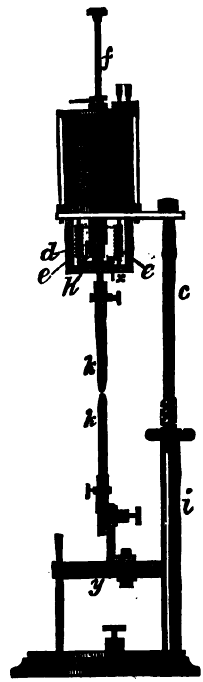

FIG. 298.—BRUSH'S ARC LAMP.

562. Electric Motors.—When the armature of a dynamo is revolved in the magnetic field, the currents generated in the coils react on the lines of magnetic force, and the two tend to *repel* each other, as two like magnetic poles do. It is to overcome this reaction that power is required to keep the armature rotating.

This is beautifully illustrated by the Foucault disk shown in Fig. 299. The weight P sets the copper disk to spinning between the poles of the electro-magnet EE. On passing a battery current through EE, the disk stops. The reacting currents in this case are in the copper disk. By substituting a model steam-engine for the weight and cord, the experiment is extended and becomes very entertaining.

563. Principle of the Motor.—If a current from a separate source be sent through the armature of a dynamo by way of the brushes and commutator, and at the same time

through the coils of the field-magnets, the repulsion between the armature and the magnet-poles causes the armature to rotate backward. If separate currents be sent

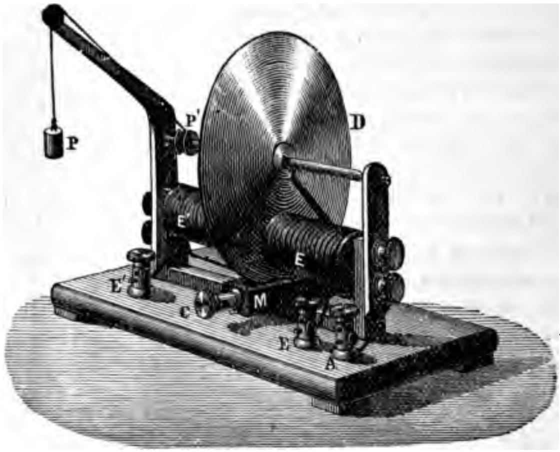

FIG. 299.—CUTTING LINES OF FORCE.

through the field-magnets and the armature, so that the polarity of one will be reversed, the armature will revolve forward. In either case we have an *electric motor*,—*i.e.*, an electric motor is in all respects like a dynamo, but, instead of supplying a current, it is supplied *with* a current. Fig. 297 is the armature made by the Edison General Electric Company for *both generator and motor.*

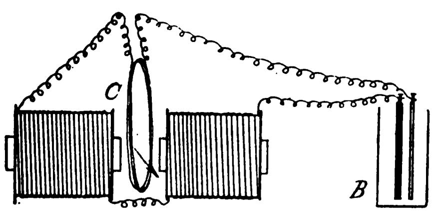

FIG. 300.—PRINCIPLE OF ELECTRIC MOTOR.

Experiment 181.—If the coil of wire used in Experiment 180 be suspended between the poles of the electro-magnet, and a battery-current be passed through both, the coil will be repelled, as shown in

Fig. 300. If the connection with the coil be reversed, it will be attracted.

564. Fig. 290 represents the reversible motor of the Keystone Electric Company. All electric motors run rapidly, and the machinery connected with them is geared to lower speed. The motor represented in the figure is for a hotel elevator. With a connection to a car-axle, it would represent a street-car motor.

565. An electric motor implies a current, and that implies a generator, which in turn implies power and motion. While the electric motor is a striking example of the transformation of energy, it can never quite yield the power sent into the generator (dynamo) by the engine which drives it. It can, therefore, not be profitably employed where the original power can as well be applied directly.

566. **Uses of Electric Motors.**—While the above is correct as a general statement, and where much power is required, there are cases in which the electric motor is convenient and economical. Being clean and noiseless, it may be used in houses and stores, for operating sewing-machines, churns, coffee-mills, etc., where steam would be inconvenient. In a town where a single large plant furnishes the current, it is always ready, and is an expense to the consumer only while being used. It furnishes a convenient method of utilizing water-power and conveying it to some distance. The water drives the dynamo, the current is distributed for lighting and for motor purposes.

567. **Electric Railways.**—In locomotion by electricity, the power for the motor must be furnished by a battery carried with the carriage or car, or it must be supplied by a conductor extending along the route from a dynamo. A voltaic battery consuming zinc is so expensive that a secondary or "storage" battery is the only one that can be considered. Street-car lines are operated upon this plan, and road carriages have been so propelled as an experiment. Cars that use the dynamo-current direct are, however, found to answer their purpose better. In such case, the current is conveyed from the dynamo to the cars upon the line in various ways. One track may be insulated, and the current flow through the wheel and axle of the car to the motor. This is dangerous to persons who may happen to touch the track, and dust on the track interferes with conduction. A conducting wire may be laid underground, and the current taken off by a "shoe," which is attached to the motor and slides along the wire; or the conductor may be strung overhead, and the current conveyed to the car by an arm ending in a metal wheel or "trolley," which rolls on the wire. In either case the current flows from the motor to the

tracks, and is so carried back to the station. The track is not insulated, so that the current is really *grounded* and the track is safe.

568. **The Many Useful Purposes** to which the dynamo and motor are applied are increasing so rapidly that no text-book could pretend to enumerate them, and the same may be said of the applications in general of electricity. The dynamo suggests lights and motors. It is used for electro-plating, metallurgy, and welding, and the largest of our telegraph systems are introducing it instead of the battery. The rapidity with which the electric current travels renders it pre-eminently adapted to signalling, which, of course, includes all varieties of telegraphing and telephoning, as well as the modes of sending and setting signals which add safety to our railroad travelling. It is hard to find a department of our arts and industries which is not being benefited by this little-understood form of energy!

V.—RADIANT MATTER.

569. **Striæ in Geissler Tubes.**—In the narrow part of a Geissler tube are generally to be seen distinct cross-wise striæ. When the exhaustion is not very complete, these striæ, or alternate light and dark bands, are quite close together, and as the exhaustion proceeds, the distance between them increases. The molecules of air left in the tube are considered carriers of the electric charge from pole to pole through the tube. No particle, however, moves the whole length; but each carries its charge a short distance, gives it up to another, and immediately returns, thus keeping up a rapid vibration. The bright bands are considered the places where most of the molecules thus meet and rebound, and the distance between these bands is the *mean free path* of the molecules.

570. **Radiant Matter of Dr. Crookes.**—The phenomena of Geissler tubes, including the striæ, are well observed in tubes exhausted till they contain but about $\frac{1}{850}$ of the original air or gas. By continuing the exhaustion till only about $\frac{1}{1,000,000}$ of the original gas remains, quite distinct phenomena are observed. The molecules seem no longer to act on one another, but all move in independent parallel or radiating straight lines until stopped by the sides of the

vessel. As the defined property of a gas is the repellent action between the molecules, and as the molecules here move independently of one another, Dr. Crookes, the discoverer of the facts, considers vacua with a tension of not more than $\frac{1}{1,000,000}$ of the atmosphere as a fourth state of matter (Art. 45), and calls it " radiant matter."

A very few of the phenomena of these highly-exhausted tubes are here described. Many more might be. Time and further research may or may not confirm the proposition that matter exists in four states, viz., solid, liquid, gaseous, and radiant.

571. Radiant Matter repelled from a Negative Electrode.—The properties of radiant matter are best studied by means of the discharge of an induction-coil. The molecules are repelled from the *negative* pole, indicating that in their natural condition they are in a negatively electrified state.[1] When the negative pole is made in the

FIG. 301.—SHELL TUBE.

shape of a plate with considerable surface, they are repelled from the surface at right angles to it, otherwise they take the general direction indicated by the entrance of the negative wire.

572. Phosphorescence produced by Radiant Matter.—The particles of radiant matter produce a bright phosphorescence where they strike. Fig. 301 shows the form of a tube with which this is

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[1] It might be remarked that the only substances which can be reduced to the condition of radiant matter are those elements which have long been known as the non-metallic or electro-negative elements.

beautifully illustrated. Before being exhausted, the tube has had a collection of rubies, shells, etc., placed in it. On passing the discharge by means of the wires shown, the mineral collection exhibits in the dark a rich glow of mixed colors and no inconsiderable amount of light.

573. Radiant and Gaseous Matter compared.—In Fig. 302 are two bulbs which show in a striking manner the difference be-

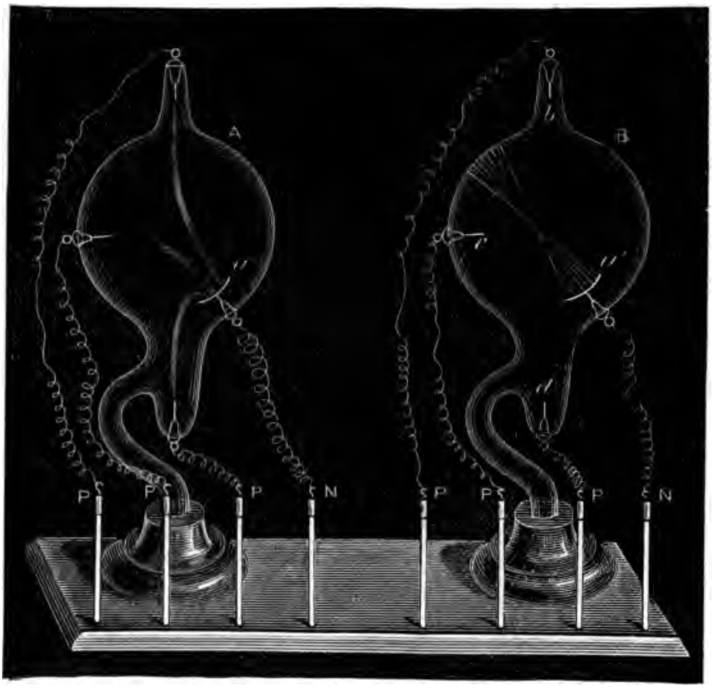

FIG. 302.—GEISSLER TUBE AND RADIANT MATTER TUBE.

tween radiant and gaseous matter. The bulb B contains radiant matter. The bulb A is an ordinary vacuum-tube containing about 3000 times as many molecules of the original air as B does. In other respects they are entirely similar. Each has a concave aluminum plate, *a* and *a′*, fastened to the sealed-in platinum wire for the *negative* electrode. Each has three other sealed-in platinum wires,

b, *c*, *d*, either of which may be made the positive electrode. The negative pole of the Ruhmkorff being connected with *a* in the tube A, the line of light indicating the path of the current extends in a tolerably direct course to that platinum wire which, for the time being, is made the positive pole, whether that be at the opposite side, the top, or the bottom of the bulb. When, however, the plate *a′* in the bulb B is made the negative pole, the particles are driven across the tube, as indicated in the figure, whether the positive pole be at *b*, *c*, or *d*, or whether it be detached entirely. The point between *c* and *b*, where the molecules strike the glass, is indicated by a bright phosphorescent patch. With a strong coil this spot soon becomes white-hot, and the glass actually melts. No such result is obtainable with ordinary vacuum-tubes.

574. The "Shadow Tube."—The glass of which most of these tubes is composed is soft German glass, which yields a bright apple-green phosphorescence on being bombarded by the particles of radiant matter. Fig. 303 represents a device for showing that the phospho-

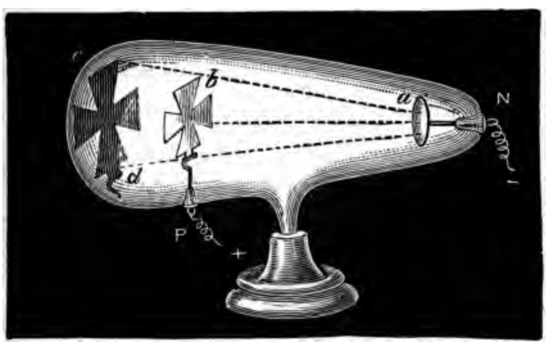

FIG. 303.—THE SHADOW TUBE.

rescence is due to this impact of the molecules. The negative pole *a* is a flat disk, which throws the molecules towards the larger end of the tube. A piece of metallic aluminum, *b*, in the form of a cross, is so placed that it intercepts some of the molecules, and the part of the glass thus protected gives no phosphorescence, but remains dark, resembling a shadow.

575. The "Railway Tube."—This impact of particles flying from the negative pole is capable of setting light machinery in motion.

Fig. 304 represents a light wheel with broad mica paddles, set on a smooth railway in a highly-exhausted tube. When the disks at the

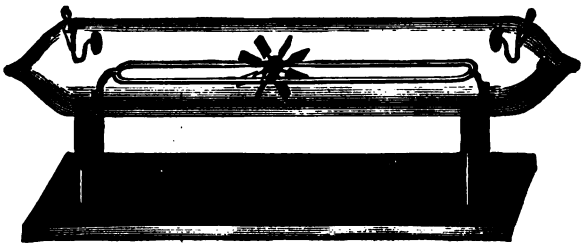

FIG. 304.—THE RAILWAY TUBE.

ends are made the poles of an induction-coil, the wheel travels from the negative towards the positive pole.

Exercises.—1. The resistance of a telegraph-wire is 12 ohms per mile. A battery of 12 Bunsen cells in series is used on a line 24 miles long: how much current flows through the wire, the E. M. F. of one cell being 1.8 volts? *Ans.* 75 milliamperes.

2. How many cells would be required to maintain a current of 75 milliamperes in the above line, if we count the internal resistance of each cell as .5 ohm, and include in the circuit 4 relays with a resistance of 104.25 ohms each? *Ans.* 30 cells.

3. Suppose a pair of dynamos driven by Niagara Falls, producing a current of 3000 volts, be connected with New York (400 miles) by a copper wire one-half inch in diameter: what is the resistance of the wire, how much current would reach New York, and what would be its working-power? *Ans.* 87.8 ohms, 34.17 amperes, 102.51 kilowatts.

4. A shunt-wound dynamo with parallel incandescent lamps develops a current of 80 volts. Each lamp has a resistance of 160 ohms. The resistance of the field-magnet shunt is 16 ohms. Disregarding the resistance of the mains, how much current flows through the external circuit, and how much through the shunt when one lamp is in circuit? (*Ans.* ½ ampere, 5 amperes.) How much through each when 200 lamps are in circuit? *Ans.* 100 amperes, 5 amperes.

5. What horse-power would be required to maintain 600 lamps in the circuit of the above dynamo, allowing 12.05 amperes for leakage and resistance of lead wires? *Ans.* 34.

SUMMARY OF CHAPTERS VIII. AND IX.

Magnetism, a property first observed in loadstone, may be communicated to iron and steel by contact with a magnet, or by the proximity of an electric current.

The attractive power of a magnet resides mainly in the poles, of *which there are two*, one north and one south, in every magnet.

Iron placed near a magnet is, while there, a magnet by induction.

Steel, magnetized by contact, by induction, or by electric currents, is a *permanent* magnet; iron is magnetic only while the magnetizing influence continues.

A magnet free to move takes a nearly north-and-south direction.

If a steel magnet be cut into any number of pieces, each piece is a magnet with two poles. This leads to the conclusion that polarity is possessed by each particle of a magnet.

The space strongly influenced by a magnet is the magnetic field.

A body rubbed with suitable material exhibits electrical phenomena.

Similar magnetic poles and similar electric charges *repel* each other, and dissimilar *attract* each other.

When two bodies are in such condition that electricity tends to pass from one to the other, there is a difference of *potential* between them.

The potential of the earth is taken as 0. A body charged with positive electricity has a + potential, and a body charged with negative electricity has a — potential.

The potential of a conductor is the same at all points of its surface.

The charge lies entirely on the *surface* of a conducting body.

The electric spark is due to the heating of particles of matter by electricity passing through poor conductors.

An electrical condenser consists of two conductors separated by an insulator.

In the Leyden jar and other condensers, a given quantity of electricity of either sign on one side of the condenser binds an equal quantity of the opposite sign on the other side of the condenser.

Lightning is the discharge of a huge condenser.

If the attracted electricity in the earth be discharged toward the cloud by a *point* (lightning-rod), the lightning-flash may be avoided.

If two different substances be placed in a corrosive liquid, electricity accompanies the resulting chemical action. This is a Voltaic cell.

The difference of potential between the poles of a cell of any given materials is a definite quantity, and represents the difference in energy of chemical action at the two elements of the cell. This is why the E. M. F. of a perfect cell of any given pattern is invariable.

Electro-motive force is that which causes electricity to flow. The unit is the *volt*.

The unit of constant current is the *ampere*.

The unit quantity of current-electricity is the *coulomb*,—*i.e.*, the amount of electricity which a current of one ampere carries past a given point in one second.

The unit of working-power is the *watt*,—*i.e.*, the working-power of a current of one *ampere*, flowing with an E. M. F. of one *volt*.

The unit of resistance is the *ohm*.

In a wire having a resistance of one ohm, an E. M. F. of one volt will maintain a current of one ampere.

The current flowing through a conductor increases as the E. M. F. increases, and decreases as the resistance increases. This is Ohm's law.

A wire over which a current is passing is surrounded by a magnetic field. Iron placed in this field becomes magnetic, and a magnetic needle is deflected.

If the junction of two metals be heated or cooled, it gives rise to currents of "thermal" electricity.

Currents are induced in a wire or a coil of wire by any *increase or decrease of magnetic field* near it. This comprises all the cases mentioned in Arts. 537 and 541.

The Bell telephone transmits currents induced by the varying in strength of a magnet-pole placed within a coil of wire. This variation of strength is produced by the inductive reaction of an iron diaphragm vibrating very close to the pole.

The carbon transmitter sends currents induced in a secondary coil by varying the strength of the current in its primary.

Telephones use electro-magnets and iron diaphragms as receivers.

If a wire be moved across the lines of force in a magnetic field, a current tends to flow through it. This is the principle of the dynamo.

For arc lights a comparatively small amount of current of high E. M. F. is required. This is produced by revolving a series-wound armature between the poles of series-wound electro-magnets.

Incandescent lights, electric motors, etc., require a strong current of low E. M. F. This is obtained by revolving a parallel-wound armature between the poles of shunt-wound magnets.

The E. M. F. of current generated by a given dynamo depends upon the strength of current flowing around the field-magnets, and the speed of rotation of the armature.

The amount of current supplied by a dynamo running at a given speed depends upon the *size of the conductors* which it follows.

A coil of wire through which a current flows is repelled from or attracted towards a similar current-bearing coil, on the principle of magnetic action. This is the principle of the electric motor.

The name "radiant matter" is applied to matter so rarefied that the molecules no longer exert a repellent action on one another as particles of a gas do, but move independently of one another.

CHAPTER X.

METEOROLOGY.

576. **Meteorology** treats of the atmosphere and the phenomena there noticeable.[1]

577. **Climate.**—Climate means the conditions of the atmosphere, particularly its states of heat and moisture that exist at any place.

578. **Causes of Climate.**—The causes which affect the climate are principally (1) the distance from the equator, (2) the height above the sea, (3) the distance from the sea, and (4) the prevailing winds.

579. **Latitude of Place.**—It is familiar to all that the nearer a country is to the equator, as a rule, the hotter it is. The reason[2] of this is that the sun shines directly down on the torrid zone, while away from it it shines obliquely and its rays are spread over a great area.

580. **Height above the Sea.**—As we rise above the sea-level, it usually becomes colder. Those who have gone up in balloons speak of the intense cold in the upper regions of the air. The cause of this is that in the rare air the body gives off more heat than it receives. Near the sea-level the dense and moist air serves as a blanket to keep in the heat which the earth receives from the sun. When the sun is shining directly on a mountain it may seem quite

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[1] The word is derived from Greek words signifying "the science of things above the earth." It has no special reference to meteors or shooting-stars.

[2] For a fuller explanation, see Sharpless and Philips's Astronomy, p 92.

warm, for then heat is being taken in; but as soon as a cloud passes over, or the sun sets, the radiation of heat begins, and great cold results. An Alpine traveller has said that the mercury in a black bulb thermometer indicated 132° while in the shade it was only 22°.

Why have a black bulb thermometer?

There is a temporary exception to this rule under certain conditions. On a cold, still morning the thermometer will indicate a lower level in the valleys than on the surrounding hills. This is because the cold air, being heavier, sinks to the lowest level.

581. **Proximity to the Ocean.**—The temperature of a country near the sea varies much less in a year than that of one farther inland.

The cause of this is largely the same as that explained in the preceding paragraph. When the sun's heat-rays fall on land they do not penetrate to any great depth. When the sun sets, or gets low down in winter, the slight amount of heat stored up on the surface of the soil is quickly lost by radiation, and cold weather sets in.

The heat-rays penetrate much more deeply into the water. Near the equator it is believed they affect its temperature to a depth of nearly 600 feet. Water has also great capacity for retaining heat. Hence it stores up large quantities during daytime and in the summer season, and parts with it slowly at night and during the winter. It therefore tends to preserve a more uniform temperature throughout the year, and this affects the climate of the lands bordering on it.

582. **Character of Ground.**—A sandy or stony country, as a desert, becomes quickly heated when exposed to direct rays, and as quickly cools off after they are removed, while a country covered with vegetation retains its heat much longer. Evaporation from the surface of the leaves *also* uses up some heat, so that a fertile and productive

country has a more equable temperature than a sterile one.

583. **Direction of Winds.**—The direction of the prevailing winds also influences very considerably the character of the climate. The causes which affect the direction of the winds will be explained farther on. Since winds bring the atmosphere of the places which they have traversed, if the prevailing direction in the Northern hemisphere is from the south, the weather will be warm, and if from the north, cold, as compared with that of other countries of the same latitude. If the wind blows in from the sea, the air will be moist, and if from off the land, dry.

As the ocean is more uniform in temperature than the land, winds from off it will be of nearly the same character the year through, while a country, even if near the sea, which is frequently subjected to winds from the interior will vary greatly in climate in the different seasons.

584. **Local Causes.**—There are other causes of climate more local in their character. If a place has a south frontage, so that it is exposed to the more direct rays of the sun, and is shielded from the cold north winds, its average temperature will be higher, and *vice versa.*

In Arctic regions the extreme cold is much modified by the freezing of the large masses of water. The amount of latent heat liberated in the freezing of water (Art. 368) is enormous, being 80 Calories for each kilogram of water, enough to raise the temperature of 33.7 kilograms of air (about 1000 cubic feet) 10° Cen., or 18° Fah.

The exposure to the effects of ocean currents also produces a great effect on the climate. Water, as we have seen, has great power to store up heat. If a current of warm water flows against the shore, the heat is largely given out, and the temperature of the *land* is *raised.* The Gulf Stream leaves Florida with a temperature of about 80°. When it completes its circulation and again reaches the torrid zone, its temperature is 40°. These forty degrees of heat have

been given to the land, chiefly Western Europe, thus raising its temperature considerably above that of countries of the same latitude in America.

585. **Interference of Causes.**—It will thus be seen that a great many causes go to produce the climate of any place. It is often impossible to tell how many of them are in operation. Sometimes they work against one another to produce opposite results. All countries in the torrid zone are not hot, and sometimes we find places at high elevation which are not very cold. But by a careful consideration of the circumstances it can usually be found out how to account for any climate.

THE ATMOSPHERE.

586. **Weight of the Atmosphere.**—The barometer, as we have seen, indicates the weight of the atmosphere. If it be watched closely, it will be seen to vary slightly through the day. By taking the mean of several readings we get the average height for the day. By taking the mean of these averages for different days we obtain the average for the year. This yearly average differs at different places.

587. **Variations.**—The average for one month is not the same as that for others. It is usually higher in winter than in summer, and the variation is more marked as we approach the equator. The highest points for the day are about 10 A.M. and 10 P.M., and the lowest six hours from these. The daily fluctuation is also greatest at the equator.

588. **Irregular Changes.**—But, besides these periodical changes, which are very small, there are irregular ones, which are of much greater consequence and magnitude. It is by them that we are able in some degree to predict the weather. As vapor of water is lighter than air, its admixture with the air causes the mass to become lighter and to produce a fall of the barometer. A fall of the barometer,

then, usually indicates the increase of the amount of moisture in the air, and, as such, is an indication of rain. The words "fair," etc., printed on barometers, mean nothing, because the height of the mercury varies with the locality and other things, and the barometer pointing to "fair" in one place would in another, during exactly the same weather, point to "foul." A sudden descent is generally an indication of an approaching storm, and a sudden rise, of clear weather. But it must be borne in mind that the barometer can indicate a storm only after the moisture is actually in the atmosphere.

589. **Uncertainty of Predictions founded on the Barometer.**—There are so many other causes affecting the height of the barometer besides the moisture in the atmosphere, that meteorologists do not consider that it alone is a safe guide for the prediction of storms. The direction of the winds and the appearances of the clouds must also be taken into account in connection with it, so that, while it is not useless, its heights are not considered in themselves sufficient grounds for predicting the weather. When properly combined with other indications they certainly afford some clue.

590. **Isobaric Lines.**—If the heights of barometers in different parts of the country are observed at exactly the same time, as is done in the signal stations of the United States, and if all the stations which have the same barometric readings are connected by lines, it will usually be found that these are roughly parallel to one another, and frequently are curves enclosing certain territory where the barometer is highest or lowest. These lines are called *isobaric lines.* They change in position rapidly from time to time, and their changes are among the facts relied upon by the head of the Signal Service Bureau to predict the weather. These lines are shown in Fig. 305.

591. **Causes of Changes of Temperature.**—The air becomes heated because (1) it absorbs some of the heat which

passes through it as it comes from the sun; (2) because it absorbs heat which the earth is radiating into space; and (3) because it comes in contact with bodies on the earth

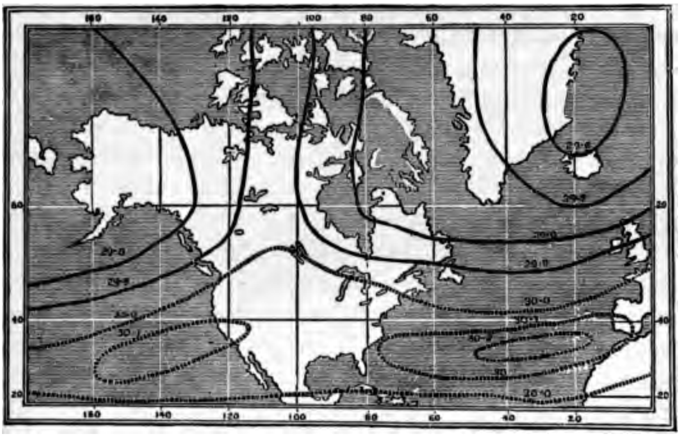

FIG. 305.—ISOBARIC LINES.

which are more or less heated. The second and third of these causes are not subject to any very sudden variations, but the first changes with all the positions of the sun with respect to the observer.

A fourth cause of change of temperature, of less consequence, is the freezing or evaporation of water. When the air is in such a dry state as to cause much evaporation, the change abstracts heat from the air, and cold is produced. When it is already charged with moisture, evaporation ceases. Every one has experienced how much hotter the air feels when moist. This is due to the fact that it does not evaporate the perspiration of the body and so cause coolness. On the other hand, when freezing or condensation is going on, heat is, as it were, squeezed out of the water, and goes into the atmosphere, raising its temperature. This, probably, explains why the Northern hemisphere is, on the average, about three degrees warmer than

the Southern. The great amount of water in the Southern hemisphere makes evaporation, which causes cold.

Clouds at a small height above the earth keep it from losing its heat in space, so that cloudy weather is never the coldest. In a similar way, a sheet or a newspaper put over a plant will protect it in frosty weather by retaining its own warmth and that of the earth.

Our clothing is as much for the purpose of keeping in the heat of the body as of keeping out the cold of winter.

592. **Effect of Clouds.**—"The temperature varies much less over cloudy than over clear districts; it varies less in low than in elevated regions; it is warmer on one side of an area of high or low pressure than on the other, and generally warmer in advance of any storm-centre and colder in the rear."[1]

593. **Hottest and Coldest Months.**—The hottest month in the year is August, and the coldest is January. These do not coincide with the times when the sun is at his position of greatest and least power, which are about the 20th of June and the 20th of December. But for some time after the 20th of December the earth is still radiating heat more rapidly than it is taking it in, and hence continues to grow cooler; and for some time after the 20th of June the earth receives more heat than it radiates, and so continues to grow hotter.

For the same reasons the highest daily temperature occurs, on the average, at 2 P.M., and the lowest at 4 A.M.

594. **Position of Thermometer.**—By the temperature of the atmosphere we mean the temperature in the shade. A thermometer to record this should, therefore, be protected from the direct rays of the sun, and from radiation from walls and other bodies liable to become heated.

595. **Isothermal Lines.**—If all the places on the earth having the same mean annual temperature be joined, these

[1] Circular of the Signal Bureau, U.S.A.

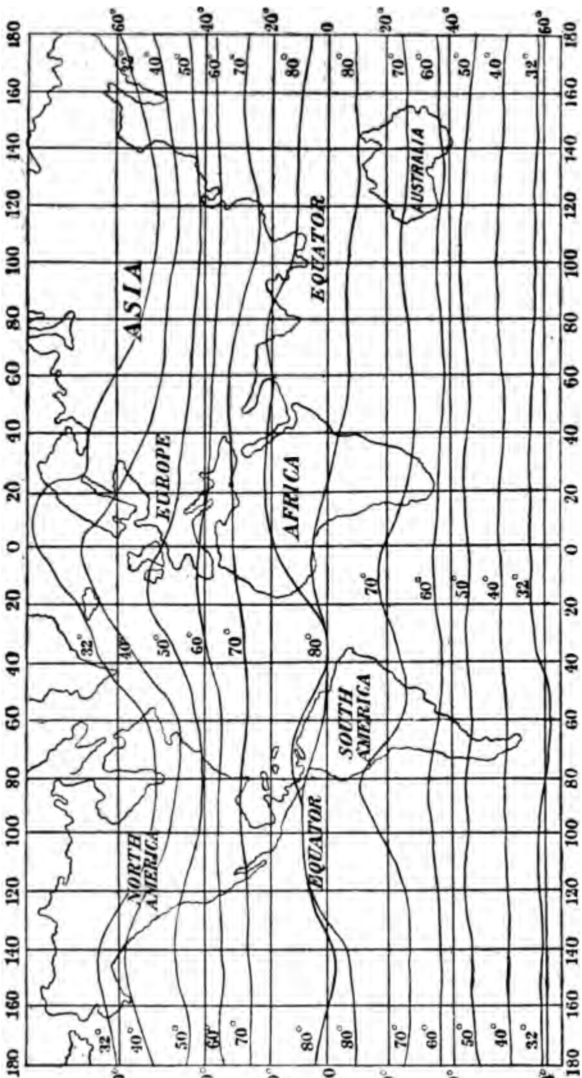

FIG. 306.—ISOTHERMAL LINES.

lines are called *isothermal lines.* Roughly speaking, they are parallel with the equator, and agree with parallels of latitude. But local circumstances affect this considerably. Fig. 306 shows the isothermal lines. The figures on them give the mean temperature for the year of all the points through which they pass. It will be observed how the Gulf Stream deflects the lines to the north by raising the temperature of the Atlantic Ocean, and how the warm air from the Pacific raises the temperature of the Western United States.

596. **Moisture in the Atmosphere.**—The air is porous, and particles of vapor of water occupy these pores. When heated, the air expands, and the pores are enlarged, so that more room exists for vapor. When the pores are full of moisture, the air is said to be *saturated.* If the temperature is raised, the same air is not saturated; if it is lowered, some of the moisture is squeezed out, and shows itself as mist, dew, frost, rain, hail, snow, or clouds.

597. **Relative Humidity.**—The capacity of the air to hold water, then, depends on its temperature. The absolute amount of moisture is not measured by meteorologists, only the *percentage of full saturation.* This is called the *relative humidity.* If the air is just half full of moisture, the relative humidity is 50; if full, 100; if absolutely dry, 0; but if, while the amount of moisture remains the same, the temperature is raised, the relative humidity is lowered.

598. **Dew-Point.**—If a certain amount of moisture exists in the atmosphere, the air can be cooled down to such a temperature that it will be saturated. This temperature is the *dew-point.* It is not uniform, but varies with the humidity and temperature of the air. The air is usually not fully saturated with moisture at the temperature which exists. The dew-point in ordinary clear weather is about 10° below the actual temperature, and in exceptionally dry times it is as much as 30° below in this climate. By this we mean that ordinary air must be diminished in tem-

ature 10° before it will be saturated and dew or clouds will begin to form.

599. **Hygrometer.**—The relative humidity of the air is determined by an instrument called the *hygrometer*.

Experiment 182.—Buy two thermometers and place them side by side. Wrap the bulb of one in a candle-wick, which passes down into a vessel of water so close that the wick around the bulb will always be wet. The "wet-bulb thermometer" will show a lower temperature than the "dry-bulb thermometer," for evaporation from the wick cools the bulb and the mercury in the tube. The amount of this evaporation will depend on the dryness of the air. If it is saturated, there will be no evaporation, and the two thermometers will register the same. If the air is very dry, much evaporation will result, and there will be a great difference. From the readings of the two thermometers it is possible to calculate the absolute amount of moisture in the air, the relative humidity, and the dew-point.

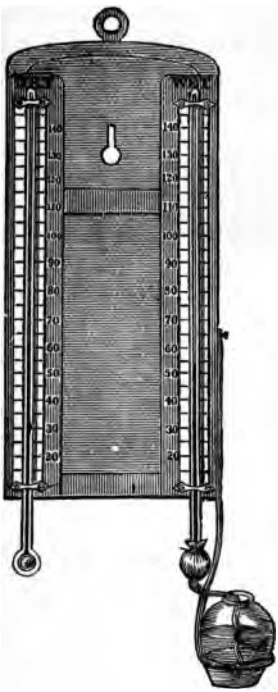

FIG. 307.—HYGROMETER.

600. **Variation of Moisture.**—The amount of vapor in the atmosphere varies with the time of day, being greatest during the latter part of the afternoon, and least during the latter part of the night. This is due to the evaporation which goes on while the sun is shining, which adds to the moisture in the air through the day, and to the condensation of moisture which results from the lowering of temperature during the night. For similar reasons the amount is greater in summer than in winter. It is also greater near the earth than in the higher regions of the air, though no air has been found entirely free from moisture. Up to a height of from 2000 to 3000 feet *there is*, however, little, if any, decrease in the humidity.

"There is an increase of moisture near bodies of warm water, fields of snow, extensive forests and meadows, etc., as compared with dry plains and rocky mountains. The humidity will be found large in advance of storm-centres, and small in their rear. It will be greater over warm cloudy districts than where cold and clear weather prevails. Certain winds will be found to be moister than others. The west and northwest are generally the driest in the Mississippi Valley. Dryness will be found attending clearing-up weather. Dampness or a large increase of relative humidity accompanies threatening weather as an almost invariable premonition."[1]

601. **Indian Summer.**—The haziness which is noticed in the atmosphere, particularly during "Indian summer," is largely due to an excess of dust or smoke. The fine particles composing this dust and smoke remain suspended in the air for a long time, and float long distances, especially in the autumn months when we do not usually have storms of rain or snow which would wash them out.

602. **Dew.**—The foliage of plants, the grass, and all things exposed to the air at night quickly lose their heat. They cool the air in immediate contact with them below the dew-point, and, it being no longer able to hold the vapor, this is deposited on the cold bodies. This is *dew.* A pitcher of ice-water will collect dew on its surface from a similar cause.

A clear night favors the deposition of dew, for when clouds are above the earth they retain the heat, so that the grass is not cooled below the dew-point. A comparatively still night favors it, because in a strong breeze no portion of the atmosphere is long enough in contact with the bodies to be sufficiently cooled. Great relative humidity favors it, for then the dew-point is not much below the ordinary temperature, and but little cooling suffices.

[1] Circular of Signal Bureau, U.S.A.

603. **Frost.**—Frost is frozen vapor or frozen dew. The vapor freezes in the air, and then settles to the ground in the form of little crystals. Hence it is necessary for the temperature to be as low as 32° at the place of freezing in order for frost to be formed. It is often cold enough to make frost in the valleys when the thermometer a little higher up indicates a higher temperature.

604. **Fog.**—When a large mass of air is cooled below the dew-point, all the vapor which it cannot contain becomes visible. When this is near the earth it is called a *fog* or *mist.* This cooling may be the result of a cold wind blowing in from the north on air nearly saturated, or of the presence of a bog or lake, which keeps the air cool at a certain spot. In the latter case the fog is permanent, while its particles may be rapidly changing. As soon as a mass of air blows into this position it is cooled down so as to make its vapor visible, and when it goes out at the other side the temperature is raised so that it hides it again. A fog usually hangs over the banks of Newfoundland, because there the cold and warm currents meet, and the warm air is cooled below the dew-point. It is also seen over rivers, on account of their cooling effect on the air.

605. **Fog, Particles of Liquid.**—Particles of vapor are transparent, and when they lie between the particles of air they do not obstruct the view. When, however, they are not thus placed, they collect in little drops, which float in the air and obstruct the view, because the light-rays are lost by their numerous reflections from one to the other. In the same way glass is transparent, but a vessel filled with broken glass is opaque. In the condensation which occurs when fog is formed, the vapor changes from a gaseous body to a liquid body. The change may be seen at the spout of a tea-kettle. Close to the orifice nothing is seen, for the steam is a transparent gas. When it goes out a little space it is cooled below the dew-point, and liquid vapor of water becomes visible.

606. **Cloud.**—When this condensation goes on in the upper regions of the atmosphere, a *cloud* is formed. A cloud is simply a fog or mist at some elevation above the earth. When we ascend a mountain we often enter a cloud, and no distinction from a mist is noticed. Clouds are apt to hang around mountain-tops, for the cold peaks lower the temperature of the air, and as fast as it rises to pass over them it is cooled below the dew-point. When it descends the opposite side it becomes warm again, and the cloud disappears from view. While the cloud apparently remains fixed in position, its particles are constantly changing.

607. **Causes of Clouds.**—A cloud may also be formed by a cold wind blowing on warmer air, or by warmer air blowing into a colder region, or by an ascending current of air expanding and so causing cold (Art. 367). The latter cause is probably the most common. The vapor formed by the action of the sun upon the waters of the earth tends by its own expansive force to rise above the earth; as it rises it reaches rarer strata of air, and so expands more rapidly. This expansion causes cold, and, besides this, the air itself is colder as we rise higher. The vapor is then changed from invisible vapor to the little particles of water which constitute cloud.

608. **Forms of Clouds.**—As the cloud-particles are heavier than the air, they gradually sink. They would fall to the ground did they not come into warmer air, by which they are again converted into invisible vapor. As soon as they get down to a stratum which raises their temperature above the dew-point, they disappear from view. This explains why certain clouds have flat bases while their tops are heaped up in masses like mountains. This form of cloud has often great thickness. The bottom may not be over a half-mile from the earth, but the top sometimes reaches the height of four miles. In general, the thickness of clouds is not more than a half-mile, and they vary from a half-mile to five miles above the surface of the earth.

There is frequently just as much vapor below the cloud as in them, but the warmer temperature prevents it from being seen.

Questions.—When you build a fire in a damp room, do you decrease the amount of moisture in the room? Why is the room drier? Is it the visible or the invisible vapor that gives the idea of dampness?

609. **Classes of Clouds.**—Clouds are usually divided into four main classes,—*cirrus*, *cumulus*, *stratus*, and *nimbus*.

610. **Cirrus.**—The *cirrus* clouds are the light, feathery masses which float in the air, scarcely screening the sun. They are believed to be composed of small particles of ice or snow floating at a great height. They sometimes betoken the coming of a storm, though usually nothing ever falls from them.

611. **Cumulus.**—The *cumulus* or "heap" clouds are clouds which are common in summer-time in fair weather. They are the clouds with flat bases and hemispherical tops, mentioned in Paragraph 608. They are the tops of columns of vapor reaching down to the earth which become visible at a height where the temperature falls below the dew-point. The shapes of these clouds are best seen through a piece of blue glass, which diminishes some of the glare of their light.

612. **Stratus.**—The *stratus* clouds are those which are seen in lines stretched along parallel to the horizon. When overhead, they cover the sky with a cloud of uniform darkness. They are near the earth, and of no great thickness.

613. **Nimbus.**—The *nimbus* are heavy black clouds, from which rain falls.

614. **Mixed Classes.**—There are often observed clouds which partake of the character of two or more kinds; these are named *cirro-stratus*, *cumulo-stratus*, etc.

615. **Disappearance of Clouds.**—Clouds form and disappear in the sky while we are looking at them. The clearing up after a storm is not so much the result of the clouds

blowing away as of their disappearance by being changed to invisible vapor by a drier atmosphere.

616. **Clouds around a Storm.**—"Two or more layers of clouds almost invariably coexist wherever extended rain-storms prevail, the upper layer stretching far in advance of the lower, but stretching down to it where rain is falling most abundantly. In the rear of this area cumulus clouds are abundant. Cumulus and cirrus clouds are not inconsistent with the idea of clear or fair weather. Cirro-stratus almost invariably precede an extensive rain-storm, whether in winter or summer. The stratus will generally be found in connection with threatening weather."[1]

617. **Rain.**—When the air is suddenly cooled below the dew-point, the little particles collect in drops, and rain is formed. This sudden cooling is most readily effected by an upward current, which carries air nearly saturated to a cooler level. There is a difference of about 35° between the air at the surface and the air two miles above the surface of the earth. When the air laden with moisture from the ocean is carried landward and over a mountain-top, we usually have copious rains. Another cause is the mixing of two clouds or two masses of air of different temperatures. If you mix a cubic foot of saturated air at 90° and another at 30° they will have a mean temperature of 60°; but air at this temperature will not hold all the moisture of both masses, and some must fall as rain.

618. **Amount of Rainfall.**—More rain falls at the equator than elsewhere, and the decrease is quite uniform to the poles. About 100 inches of rain fall at the equator annually. By this we mean that if all of it could be collected it would cover the surface to a depth of 100 inches. In our latitude the average rainfall is between 30 and 40 inches.

619. **Snow.**—When the vapor of the air is frozen, snow is formed. Freezing is a form of crystallization, and the

[1] Circular of Signal Bureau, U.S.A.

forms of the crystals of snow are very beautiful. To observe them well, let them fall on cold pieces of colored glass and examine them with a microscope of low power. *Do not breathe on them.*

FIG. 308.—FORMS OF SNOW-CRYSTALS.

Prof. Tyndall speaks of the snow-crystals which he saw on Monte Rosa as "a shower of frozen flowers; all of them were six-leaved; some of the leaves threw out lateral ribs like ferns; some were rounded, others arrowy and serrated; but there was no deviation from the six-leaved type."

620. **Hail.**—Hail is frozen water. It is produced during thunder-storms by the approach of a cold current, which forces upward the warm, saturated air of the lower regions. Snow is first formed, and the whirling action of the air collects this into little balls, which, as they move through the snow and vapor, become alternately coated with snow and covered with ice, gradually but rapidly growing till they reach sometimes the size of turkey-eggs. When examined, the centre is seen to consist of

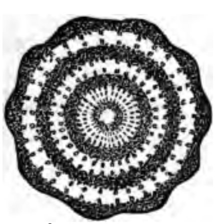

FIG. 309.—SECTION OF HAIL-STONE.

snow, and often alternate layers of snow and ice may be noticed.

621. **Wind.**—Wind is air in motion. Air having mass, when it strikes any object it presses against it, the pressure being harder the faster it moves. A wind moving at the rate of 4 miles an hour is a pleasant breeze, and presses against every square foot of surface which it strikes vertically with a force of about an ounce. A brisk wind of 25 miles per hour has a force of about 3 pounds per square foot; a very high wind of 45 miles per hour, of 10 pounds per square foot; a hurricane of 80 miles per hour, of 31 pounds per square foot.

The mean velocity of the wind in the Eastern United States is about 10 or 12 miles per hour, being more in winter than in summer, and is greatest at 2 P.M., and least at night. The daily curve is seen in Fig. 310.

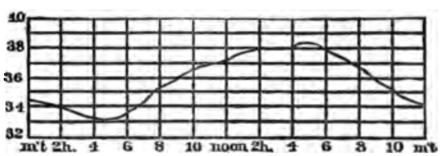

FIG. 310.—DAILY CURVE OF WIND.

622. **Cause of Winds.**—The air at the equator is heated by the direct rays of the sun, and is pushed up by the heavier cold winds from the polar regions settling down to take its place. The heated air moves as an upper current towards the poles, while the cold air moves as a surface-current towards the equator. This interchange would go on regularly and continually were it not for the rotation of the earth on its axis. A particle at the equator moves with greater velocity than one near the poles, because it has so much farther to go in the same time. The air partakes of the motion of the earth below it, and when the slowly-moving air from the higher latitudes sweeps down towards the equator it is left behind and falls back towards

the west. This produces the trade-winds of the torr zone. When the upper currents from the equator reac the temperate zones they become sufficiently cooled to f again to the surface, and, having the rapid equatori motion, they sweep ahead of the earth and form the pr vailing westerly winds of our latitude.

The extreme cold of the polar regions produces surfac currents away from the poles and upper currents towar them.

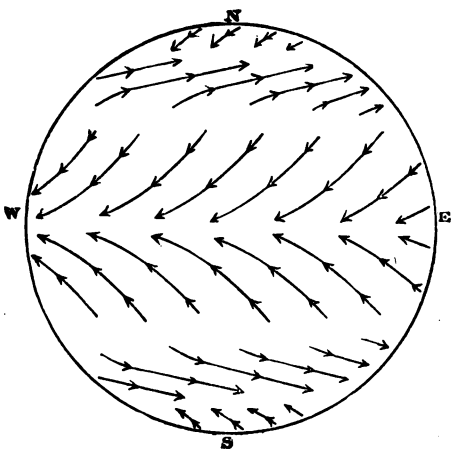

FIG. 311.—WINDS OVER THE GLOBE.

The surface-winds are shown in Fig. 311, and Fig. 312 gives the whole circulation without the effects of the earth's rotation.

623. **Variable Winds.**—These are the general systems of winds. But, as every one knows, the changes in direction and intensity of the wind are almost continuous. There are numerous local circumstances which determine particular winds. Wherever there is low pressure, as indicated by the barometer, there are surface-currents sweeping in from all around, for the equilibrium of the atmosphere *is destroyed* and a flow sets in to restore it. If any place

becomes greatly heated, the air will tend to flow into it in all directions, producing surface-currents towards, and upper currents away from, the heated place. When the heated air rises, it becomes cooled, spreads out, and falls down, and is returned again to the place whence it came.

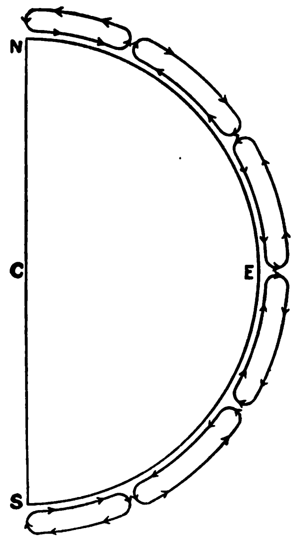

FIG. 312.—CIRCULATION IN THE AIR.

The reverse would take place around a cold centre.

624. **Land and Sea Breezes.**—During the day the land heats up more than the water, so that along the sea-coast there are usually breezes blowing in from the sea during the day. At night it loses its heat more quickly and becomes cooler than the sea, so that the breeze sets in in the opposite direction.

625. **Monsoons.**—The same cause produces the monsoons of the Indian Ocean. The regions of India become heated in their summer, and the wind sets in strongly from the Indian Ocean. In the winter the reverse is the case.

626. **Moisture a Cause of Winds.**—Another local cause of winds is the moisture in the atmosphere. As vapor of water is lighter than air, the sudden formation of cloud will tend to produce a low barometer. Winds will set in towards this centre to restore the equilibrium.

627. **Difficulty in ascertaining the Cause of Winds.**—Among all these causes it is often impossible to say which one is producing the wind at a given time and place. Its fickleness has become proverbial, and many causes doubtless operate together in producing the modifications. The changes are not the result of chance, but every particle of

air moves in obedience to the impulses which act upon it. Winds are great agents for purifying the earth and making it healthy, and a multitude of ways in which they are useful to man will suggest themselves to any one.

628. **Storm.**—A storm is a great commotion in the atmosphere. Rain, hail, or snow generally accompanies it.

629. **Effect of Heat.**—In case of the heating of a large tract, the cold air flows in from all around. The hot air rises and spreads out. This mingling of the currents often produces clouds and rain, as has been explained. This is a storm. The whole system of currents and clouds is then carried by the prevailing winds over the country. A barometer near the centre would show low pressure.

630. **Effect of Rotation of the Earth.**—Were there no rotation of the earth, the surface-air would always blow directly towards the storm-centre, and the upper air away. In the Northern hemisphere the winds coming in from the south are, by their more rapid motion with the earth around its axis, carried towards the east, and those coming in from the north are in like manner deflected towards the west. This makes them approach the centre not directly, but in a spiral curve, and creates a "cyclone." Nearly all our storms are more or less cyclonic in their character. The reverse kind of cyclone exists in the Southern hemisphere.

631. **Movement of Storms.**—The prevailing winds in the torrid zone being easterly, the storm is carried towards the west. As it recedes from the equator it reaches the region of westerly winds, by which it is borne eastward. Most of our large storms come from the west or the southwest.

This may not be the direction of the wind at the time. The wind at any time is usually directed obliquely towards the storm-centre, and this is frequently modified by local causes, so that there are all possible directions inside the storm-area. In the Atlantic States the winds commonly blow from some easterly quarter during a storm.

632. **Storm-Centre.**—In the centre of a storm there is a

calm, and sometimes clear weather. After the centre has passed, the wind shifts to the west, it often rains hard for a short time, and then clears away. When the wind shifts

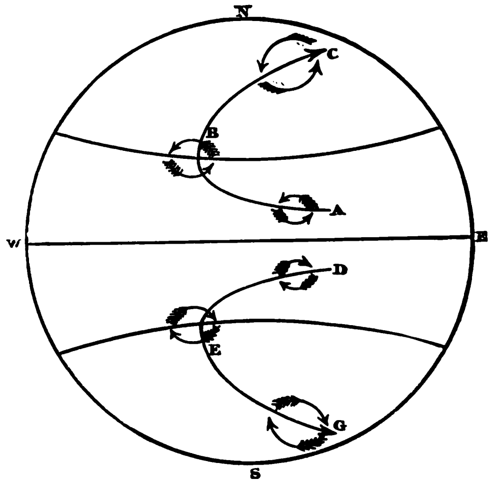

FIG. 313 —MOTION OF STORM-CENTRE AND OF AIR AROUND IT.

to the west after several days of east wind, clear weather soon follows.

633. **Direction of Wind around a Storm-Centre.**—To remember the direction of the surface-winds around a storm-centre, the student may notice that in the Northern hemisphere, to a person situated above, the motion is opposite to that of the hands of a watch.

634. **Direction of Storms.**—The direction of storms through the United States is towards the east, varying sometimes to the northeast or the southeast, and their average hourly rate of motion is 21 miles in summer and 30 in winter. They sometimes move faster than this, and sometimes remain almost stationary.

635. **Thunder-Storms.**—The storms of wind and rain of summer, often accompanied by thunder and lightning, do not move across the continent, but are local in their origin.

The heat of the sun fills the lower regions with vapor over some point, and causes it to ascend till its cooling produces cumulus clouds level at base, heaped up on top. This goes on till condensation into drops ensues and rain falls. The winds sweep the clouds along, and there is a certain amount of cyclonic tendency, but the storm does not extend far, and is soon exhausted. The electric phenomena accompanying such storms have been explained in the chapter on electricity.

636. **Cyclones.**—Frequently cyclones or hurricanes are formed in the Atlantic Ocean, near the equator, and are swept along westward, as shown in Fig. 314, then turn

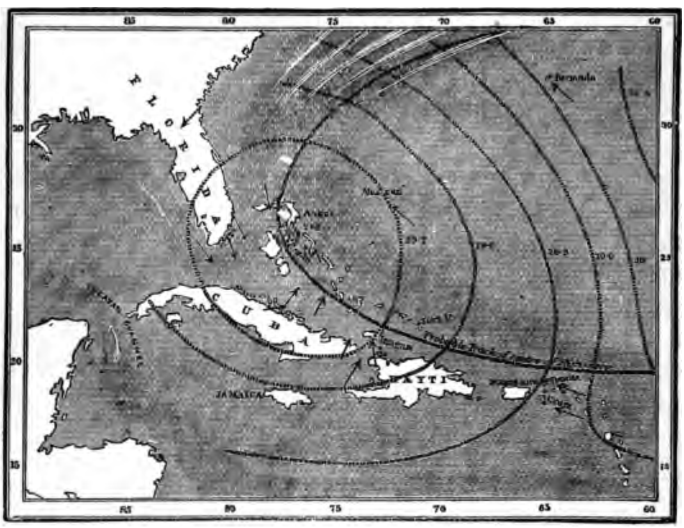

FIG. 314.—COURSE OF CYCLONES IN THE ATLANTIC OCEAN.

opposite the South Atlantic States, and are usually lost in the North Atlantic, though they sometimes doubtless reach Europe. In this case, as the storm-centre sweeps up the course of the Gulf Stream, we have east and southeast winds along our eastern coast, accompanied by heavy rain.

The eastern storms which begin at the South are usually of this class. Occasionally the storm does not turn till it reaches the Gulf of Mexico, when it moves centrally across the United States.

In the equatorial regions the cyclones are more violent, the rain is more extensive, and the wind is stronger than in the temperate zones. The energy is somewhat diminished by the distance travelled.

637. **Prediction of Storms—Signal Bureau.**—The laws governing the motions of storms are now so well established that it is possible to predict with tolerable certainty for one or two days in advance what the weather will be. This is the work of the Signal Service Bureau of the War Department of the United States Government. There are scattered over the country about one hundred stations, at each of which, three times every day, at the same instant of actual time, observations are taken by the officer in charge. These are telegraphed immediately to the chief signal officer at Washington, who in turn telegraphs many of them to some of the more important stations, from which bulletins of the prominent features are issued. These bulletins tell—

Height of the barometer;
Change since last report;
Thermometer;
Change in the last twenty-four hours;
Relative humidity;
Direction of the wind;
Velocity of the wind;
Force of the wind;
Amount of cloud;
Rainfall since last report;
State of the weather.

These bulletins are open to examination at the signal-offices and other public places in the cities and towns to which they are transmitted.

Besides the bulletins, a statement of synopses and indications is prepared at the office of the chief signal officer, and thence issued thrice daily. The press agents telegraph it over the country. This statement is given out at 1 A.M., 10 A.M., and 7 P.M. daily, Washington time.

638. **Correctness of the Indications.**—The indications nearly always prove correct. The signal officer receives reports of storms, or cold waves, or clearing weather, from the West, and their rate of travel, from which he has to predict where they will be at a given time. It is not always a simple matter. He has to take into account a variety of possible modifying circumstances, and great study and experience are needed to make it right in nine cases out of ten, which is about the record of our bureau. No other nation has so complete or well-arranged a system as ours, and it is well worth all it costs. Many vessels are protected from wreck by heeding the signals of a coming storm which are displayed along the coast, and the dwellers along the Western rivers are often saved from floods by timely notice of their approach.

639. **Weather Chart.**—The chief signal officer also issues, thrice daily, a graphic weather chart, which shows at a glance the weather all over the country at that hour. Any one, with proper care and knowledge, can forecast the weather for himself by a study of these charts.

APPENDIX.

THE METRIC SYSTEM.

The metric system of weights and measures was devised in France about the beginning of the present century. It is now in general use in most of the countries of the civilized world, and in the others is largely used in scientific work.

The unit of length in this system is the *metre*, which is equivalent to 39.37 inches. This was taken because it is one ten-millionth of the distance from the earth's equator to the pole.[1] On account of its great convenience, the system was made decimal throughout. The prefixes to denote the fractions of a unit are the Latin numerals, and are the same for all the tables, while the Greek numerals indicate the multiples of the unit in all the tables.

TABLE OF MEASURES OF LENGTH.

			Symbol.	Metric Value.	U.S. Value.
		1 millimetre,	*mm.*	.001 m.	.03937 in.
10 millimetres	=	1 centimetre,	*cm.*	.01 m.	.3937 in.
10 centimetres	=	1 decimetre,	*dm.*	.1 m.	3.937 in.
10 decimetres	=	1 metre,	*m.*	1 m.	39.37 in.
10 metres	=	1 dekametre,	*Dm.*	10 m.	32.81 ft.
10 dekametres	=	1 hectometre,	*Hm.*	100 m.	19.92 rd.
10 hectometres	=	1 kilometre,	*Km.*	1,000 m.	.6214 mi.
10 kilometres	=	1 myriametre,	*Mm.*	10,000 m	6.214 mi.

The unit of capacity is the *litre* (lee′ter); it is the quantity which a cubical box, 1 decimetre each way inside, will hold. It is equivalent to 1.0567 quarts liquid measure, or .908 quart dry measure, so that it is between our dry and liquid quarts, and does not differ

[1] The more accurate measurements of recent years have shown that the standard metre which the French adopted, and which is still used everywhere, is a trifle ($\frac{1}{5400}$) shorter than an exact ten-millionth of this distance.

greatly from either. The same measures are used for both liquid and dry measure. The table of measures of capacity is exactly the same as the one for length given above, except that *metre* is changed to *litre*. Its symbol is *l*.

The unit of weight is the *gram*; it is the weight of pure water at 39° F. which a cubical box, 1 centimetre each way inside, will hold. It is equivalent to 15.432 grains; a five-cent piece weighs 5 grams and is 2 centimetres in diameter. The table is made in the same way as before, by changing *metre* to *gram*, in the table given above. Its symbol is *g*.

In measuring surfaces the square metre, square dekametre, etc., are used. The *are* (air), which is a square dekametre, is also used, and a table is made by using it with the common prefixes.

Cubic decimetres, cubic metres, etc., are also used in measuring solids, as well as the *stere* (stair), which is a cubic metre. Its table is made in the same way as the others.

A TABLE OF SPECIFIC GRAVITIES.

Liquids.

Pure water, at 39° F.	1.000	Sulphuric Acid	1.841
Sea-water	1.026	Milk	1.032
Alcohol	.791 to .916	Mercury, at 32° F.	13.596
Ether	.716		

Solids.

Iridium	23	Brick	2 to 2.17
Platinum	21 to 22	Chalk	1.8 to 2.8
Gold	19 to 19.6	Coal, bituminous	1.02 to 1.35
Lead	11.4	" anthracite	1.36 to 1.85
Silver	10.5	Limestone	2.4 to 3.
Copper	8.6 to 8.9	Ice	.93
Brass	7.8 to 8.5	Wood, lignum-vitæ	1.34
Iron, cast	7 to 7.3	" hickory	.83 to 1.
" wrought	7.6 to 7.8	" oak	.85
Steel	7.8	" pine	.42 to .55
Glass	2.5 to 3	" cork	.24
Quartz	2.65		

Gases.

Air	1.	Hydrogen	.07
Oxygen	1.11		

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